THE UNIVERSITY OF ALBERTA

STRENGTH OF SHEAR PLATE CONNECTORS IN SLOPING GRAIN SURFACES.

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

MAY 1966

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled STRENGTH OF SHEAR PLATE CONNECTORS IN SLOPING GRAIN SURFACES, submitted by Robert David Cameron in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

In this investigation into the strength of shear plate connectors in sloping grain surfaces, the angle of grain and the direction of load in the sloping grain surface were the variables studied. A total of 192 specimens were tested to failure. 2-5/8 inch diameter shear plates and 4 inch diameter shear plates were used. The dimensions of all specimens were identical, except that the edge distance differed in the specimens using 2-5/8 inch diameter shear plates from that of the specimens using 4 inch diameter shear plates.

Results obtained indicate that:

(1) The load carrying capacity of shear plate connectors decreases as the grain angle varies from 0^{o} to 90^{o} and then increases as the grain angle varies from 90^{o} to 180^{o}.

(2) The capacity of shear plates in specimens so constructed that the plates tend to "lock-in" is higher than in specimens so constructed that the plates do not "lock-in".

(3) The effect of varying the grain angle on the slope of the load-slip curves was not well defined.

(4) For a given grain angle the capacity is changed by varying the load angle.

ACKNOWLEDGEMENTS

The author wishes to express appreciation for assistance he received from various sources.

The Canadian Institute of Timber Construction sponsored the investigation. Western Archrib Structures of Edmonton provided the materials and fabricated the specimens. Professor J. Longworth helped greatly throughout the course of the investigation and during the writing of the manuscript.

Associate Professor A. Peterson and Sessional Instructor R. B. Pinkney assisted in the photography and Messrs W. R. Browne, H. Panse, F. Rothbrust, and D. Whidden assisted in the testing programme.

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CHAPTER I

INTRODUCTION

1.1 Introductory Remarks.

Although wood is a very versatile material of construction, difficulty in obtaining adequate connections is often encountered. Even though a member may have sufficient cross-sectional dimensions to accomodate the design load, these dimensions may have to be increased in order to facilitate an adequate connection. This problem has led to a great amount of research in the field of timber joint efficiency. Many tests have been conducted in order to determine the strength characteristics of various timber joints. Such connector units as bolts, shear plates, split rings, etc., have been load tested in side grain surfaces. (4). The literature contains no reference to tests on connector units positioned in end grain surfaces or sloping grain surfaces. The present investigation was therefore undertaken to determine the strength characteristics of shear plate connector units in end grain and sloping grain surfaces.

1.2 Shear Plate Connectors.

As outlined in the Timber Construction Manual (5) shear plate connectors are of two types:

"(a) Pressed Steel Type - Pressed steel shear plates shall be manufactured from hot-rolled carbon steel, SAE 1010, meeting the requirements of the latest issue of the SAE Handbook. Each plate shall be a true circle with a flange around the edge, extending at right

angles to the face of the plate from one face only. The plate portion shall have a central hole and two small perforations on diametrically opposite sides of the hole each midway from the centre and circumference; or

(b) Malleable Iron Type - Malleable iron shear plates shall be manufactured according to the requirements of ASTM Standard A47 for Grade 35018, malleable-iron castings. Each casting shall consist of a perforated round plate with a flange extending at right angles to the face of the plate and projecting from one face only. The plate portion shall have a central bolt hole, reamed to size, with an integral hub concentric to the bolt hole and extending from the same face as the flange."

Shear plate dimensions shall be in accordance with Table I.1.

TABLE I-1

Shear Plate	2-5/8 inch Pressed Steel inches	4-inch Malleable Iron	
		3/4-inch bolt inches	7/8-inch bolt* inches
Diameter of Plate	2.62	4.02	4.02
Diameter of bolt hole	0.81	0.81	0.94
Thickness of plate	0.17	0.20	0.20
Depth of flange	0.42	0.62	0.62

*Shear plates for 7/8 inch bolts were not used in this investigation.

1.3 Mechanics of Timber Joints with Shear Plate Connectors.

In a typical joint assembly where two or more wooden members are to be joined by use of shear plates, the shear plates are placed back to back with their flanges fitting into pre-bored grooves in the wooden members and connected by means of a bolt. (Figure 1.1). As outlined in Forest Products Bulletin 865(4) the following action takes place in the joint:

The primary stresses in the wood of the tension joint shown in Figure 1.1 may be classified as shear, compression, and tension. The shaded areas indicate the principal part of the wood (A) subjected to shear, (B and C) subjected to compression, and (D) subjected to tension. For a tension joint with two shear plate connectors in opposite faces and a concentric bolt, bearing parallel to the grain of the wood, these areas can be expressed by the following formulas:

Shear area:

Within core: $2\left(\frac{\pi d_1^2}{4}\right)$

Below core: $2[d_2 e - \frac{1}{2}\left(\frac{\pi d_2^2}{4}\right) + 2\left(\frac{ae}{2}\right)]$

Compression area: $2\left(\frac{ad_2}{2}\right) + b\,(t_1 - a)$

Tension area: $t_1 w - \left[2\frac{(ad_2)}{2} + b(t_1 - a)\right]$

in which:

d_1 = inside diameter of connector,

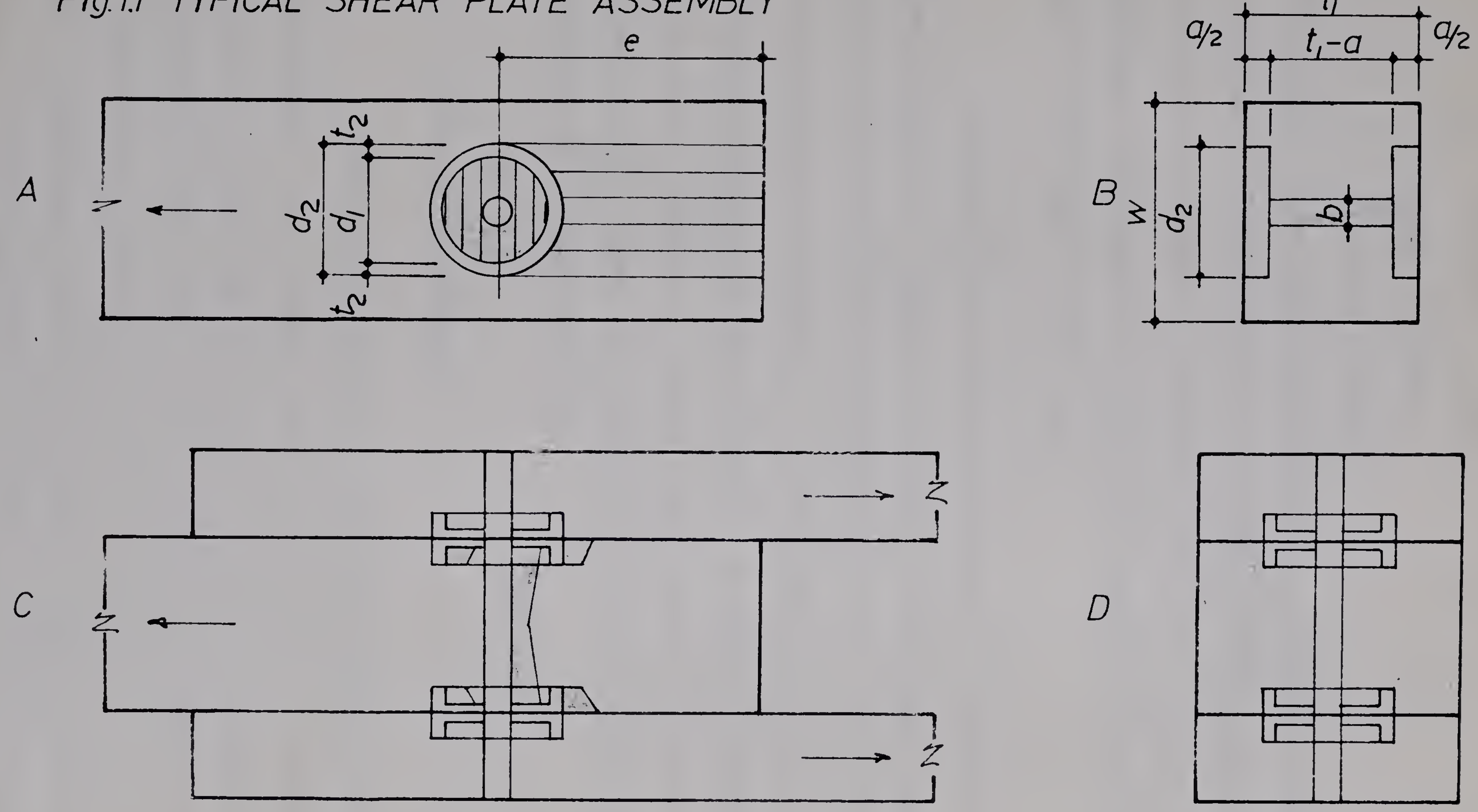
d_2 = outside diameter of connector,

e = end distance from center of connector to end of member,

a = the depth of connector unit,

b = diameter of bolt,

Fig.1.1 TYPICAL SHEAR PLATE ASSEMBLY



Detail of connector joint, showing portions of center member subject to shear (A), compression (B&C), and tension (D). Corresponding stresses, not shown, exist in the side members. [after Scholten (4)].

t_1 = thickness of member,

w = width of member,

t_2 = thickness of metal.

The strength of the joint, apart from that of the bolt and connector is obviously controlled by one or another, or some combination, of shear compression or tension. It should be noted that the bolt shall be of sufficient cross-section to effectively transfer the load from one shear plate to the other by direct shear.

In applying the theory of elasticity to the distribution of these stresses in a timber joint, nearly all the basic assumptions are upset by the anisotropic structure of the wood, by the presence of irregularities and defects such as knots and cross grain, and by the interaction between the wood and metal. A practical analysis of the behaviour of the joint, therefore, resolves itself primarily into a correlation between the test loads, the character of failure, and the mechanical properties of the wood and metal.

1.4 Design Considerations.

In the design of timber joints many variables must be taken into account. The strength of particular joint is influenced by moisture content of the wood, specific gravity of the wood (species), spacing of the connector units, end and edge distances, thickness of members, size of shear plates and connecting bolts and finally the angle of load to grain. Present day design specifications attempt to take account of these factors by applying modification factors to allowable connector unit loads for a specific shear plate and bolt size, i.e.,

$$P = X \cdot K_g \cdot K_t \cdot K_s \cdot K_m \qquad (6)$$

where: P = allowable load on a connector unit in pounds

X = allowable load in pounds on a connector unit when

$K_g = K_t = k_s = K_m = 1.00$

K_g = modification factor based on species

K_t = modification factor based on thickness

K_s = modification factor based on spacing, end distance or edge distance.

K_m = modification factor based on moisture content.

1.5 Present Investigation.

In this investigation the variables mentioned in the previous paragraph were either eliminated or an attempt was made to control their effect. Thickness, loaded end distance, unloaded end distance and edge distance variations were eliminated by using specimens of identical size. Since only one connector unit per specimen was used the effect of spacing was not a consideration. The influence of species or specific gravity was kept to a minimum by using a high grade Douglas Fir material from one shipment. The effect of variable moisture content was minimized by handling and storing all specimens in the same manner. Samples were taken to determine specific gravity and moisture content so that their influences could be measured. One bolt size was used throughout and the shear plates of different sizes were load tested in groups with results being tabulated for each group. A separate series of load tests was run to determine the effect of varying the angle of load to grain. Strength tests were made on the wood and the bolts. The influence of strength variations in the shear plates was assumed to be negligible.

CHAPTER II

OBJECT AND SCOPE

The objects of the investigation presented in this thesis were:

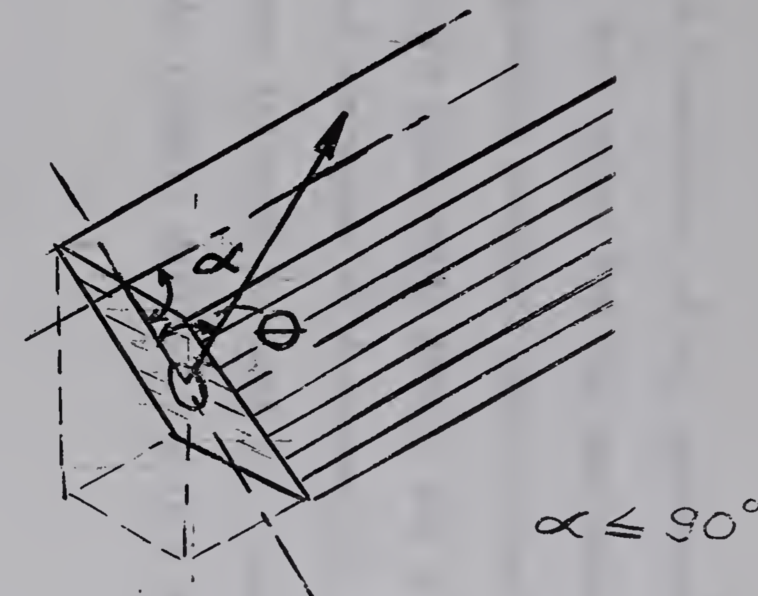
(1) To load test shear plate connectors set in sloping grain surfaces varying from side grain surface to end grain surface in order to investigate their strength characteristics up to ultimate load.

(2) To investigate the strength characteristics of shear plate connectors for varying directions of load when connectors are set in a surface which is not a side grain surface.

Thirty-two groups of six specimens each were tested. 2-5/8 inch shear plates and 4-inch plates were investigated. <u>Group 2</u> specimens contained 2-5/8 inch shear plates. <u>Group 4</u> specimens contained 4 inch shear plates. The angle between the side surface of the grain and the plane of the shear plate was varied from 0° to 180° in increments of 15° for both Group 2 and Group 4 specimens. In addition specimens containing 2-5/8 inch shear plates and having an angle of 45° between side surface of the grain and the plane of the shear plate were fabricated and load was applied at various angles in the plane of the sloping grain surface. Table II-1 gives the details of the specimens.

TABLE II-1 SCHEDULE OF SPECIMENS

Series		No. of Specimens	α°	θ°
4A1	2A1	6	0	0
4A4	2A4	6	0	90
4B1	2B1	6	15	0
4B6	2B6	6	15	180
4C1	2C1	6	30	0
4C6	2C6	6	30	180
4D1	2D1	6	45	0
	2D2	6	45	150
	2D3	6	45	120
	2D4	6	45	90
	2D5	6	45	45
4D6	2D6	6	45	180
4E1	2E1	6	60	0
4E6	2E6	6	60	180
4F1	2F1	6	75	0
4F6	2F6	6	75	180
4G1	2G1	6	90	0
4G6	2G6	6	90	180



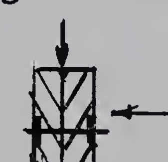
α = angle between plane of shear plate and side surface of grain or grain angle

θ = angle between load and normal to direction of laminations or load angle

Specimen Designation.

e.g. 2C14 2 - 2-5/8"φshear plates.

C - α = 30° or 30° between side surface of grain and plane of shear plate.

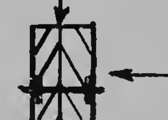


1 - θ = 0

4 - 4th specimen to be tested in series.

4C64 4 - 4"φshear plates

C - as above



6 - θ = 180°

4 - as above

The dimensions of all specimens were the same except for the width, which was larger for the specimens containing 4 inch shear plates in order to provide adequate edge distance (1). Edge distance of 2-5/8 inches for 2-5/8 inch shear plates and 3-1/2 inches for 4 inch shear plates and end distances of 4 inches for unloaded end and 8 inches for loaded end were selected to meet the requirements of the National Building Code of Canada (1965), Section 4-3-10.5.(3) for side grain surfaces.

CHAPTER III

MATERIAL PROPERTIES AND FABRICATION OF SPECIMENS

3.1 Specimen Dimensions.

After considerable preliminary testing it was decided to use the specimens as shown in Figure 3.1. The thickness of the specimens was determined on the basis of the results of the preliminary testing. An optimum thickness was used. This was the thickness at which a further increase in thickness would yield no further increase in ultimate load. The overall length of specimen was determined by practical limitations imposed in handling and fabrication.

3.2 Grading of Material.

One hundred ninety-two specimens were fabricated in thirty-two groups of six specimens each. The entire one hundred ninety-two specimens were fabricated from one lot shipment of clear Douglas Fir (Coastal region), graded as dense, select structural grade. It was considered that this high grade material was required in order that localized defects, such as knots, checks and sap pockets would be at a minimum. Since specimen sizes were relatively small, a defect in the vicinity of the shear plate would invalidate any results obtained from testing.

Grading of this material is governed by the following characteristics and limiting provisions:

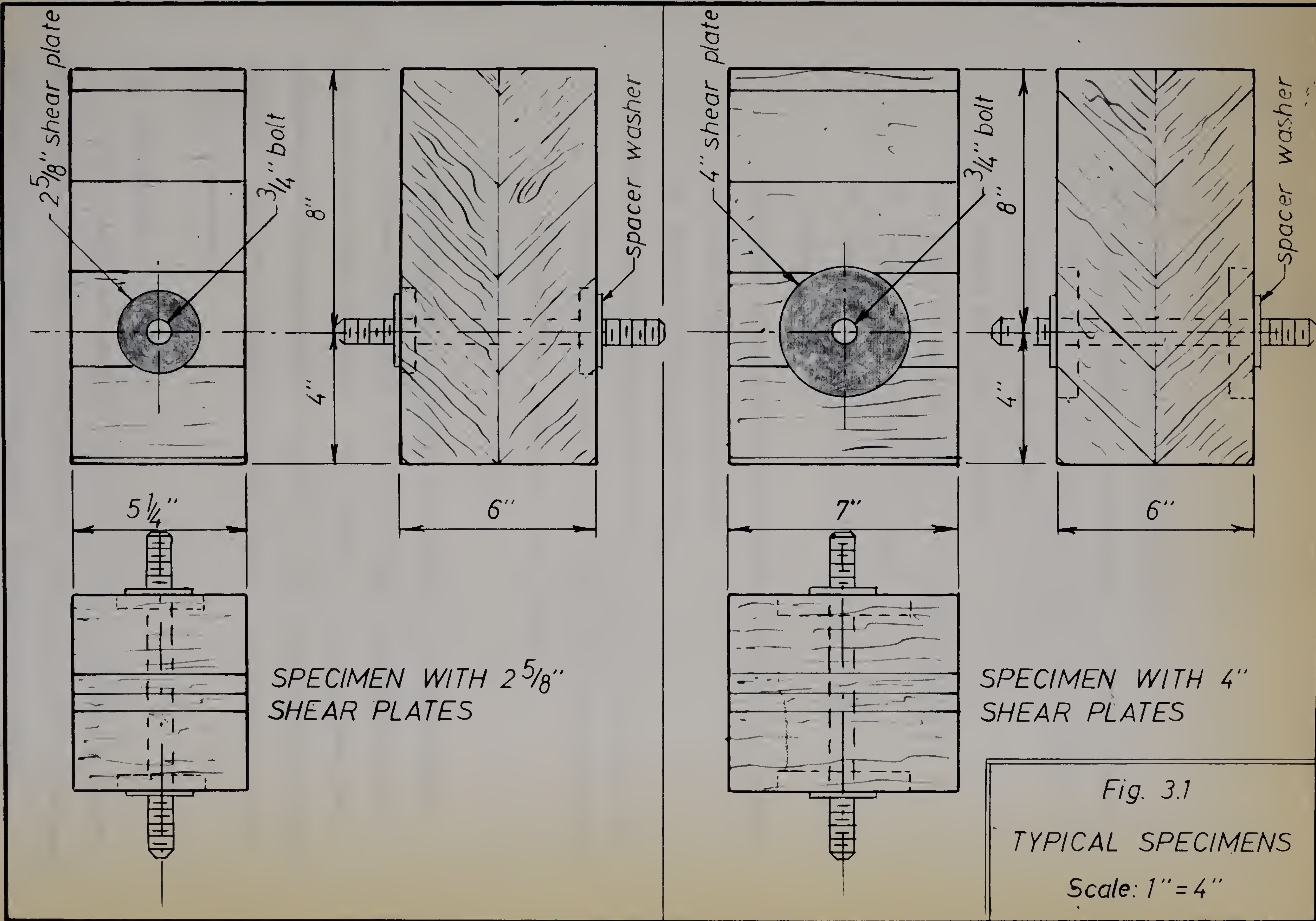


Fig. 3.1

TYPICAL SPECIMENS

Scale: 1" = 4"

(1) Splits, if present, must be very short.

(2) Checks, if present, must be single, or if opposite each other they must have a sum total equal to a maximum of approximately one quarter the thickness.

(3) Medium torn grain is allowed.

(4) Skips, if present, must be occasional and small.

(5) Medium pitch pockets are allowed.

(6) Wane with a maximum of approximately one eighth of any face is allowed.

(7) Knots, if present, must be sound, tight and well spaced.

(8) Pitch streaks may be present.

(9) Stained sapwood may be present.

(10) Slope of grain in the middle one third of the length must not exceed one inch in twelve inches and in the balance of the piece may be one inch in ten inches.

(11) Close grain must be present.

"Dense Material" in Douglas Fir averages six or more annual rings per inch and, in addition, one third or more summerwood on either one side or the other of a piece. The contrast in colour between the summerwood and springwood must be distinct. Pieces that average less than six annual rings per inch are accepted as dense if they average one half or more summerwood.

3.3 Fabrication of Specimens.

All lumber was standard stock 1-5/8 inch in thickness. Glulam sections were fabricated and slices were cut at various angles to the grain. Each test specimen consisted of two slices. One slice was rotated

180° relative to the other in order that the shear plates would act at the same angle to the grain on either side. The slices were glued and clamped, allowed to set for approximately twenty-four hours, and then trimmed to the required length. A 13/16 inch hole was then drilled through the specimen and grooves for the shear plates were cut by means of a standard grooving tool. Figure 3.2 indicates the steps followed in the fabrication of the specimens. Prior to testing, a 3/4 inch bolt, threaded on both ends, was inserted in the specimen and two shear plates were set in the grooves as shown in Figure 3.1.

3.4 Tension Tests on Bolts.

Three bolts were selcted for destructive tension tests. They were placed in the loading yokes shown in Figure 3.3. Two nuts were threaded on each end so that enough shear area on the threads would be available to prevent stripping of the threads.

An automatic recorder was used to plot the load - deformation relationship. (Figures 3.4, 3.5 and 3.6).

3.5 Compression Tests on Small Douglas Fir Specimens.

Twelve small Douglas Fir specimens were tested in compression to failure, six specimens parallel and six specimens perpendicular to the grain of the wood. Mercer dials and SR4 strain gages were used to measure strains. (See Figure 3.7). Results are plotted in Figures 3.8 and 3.9.

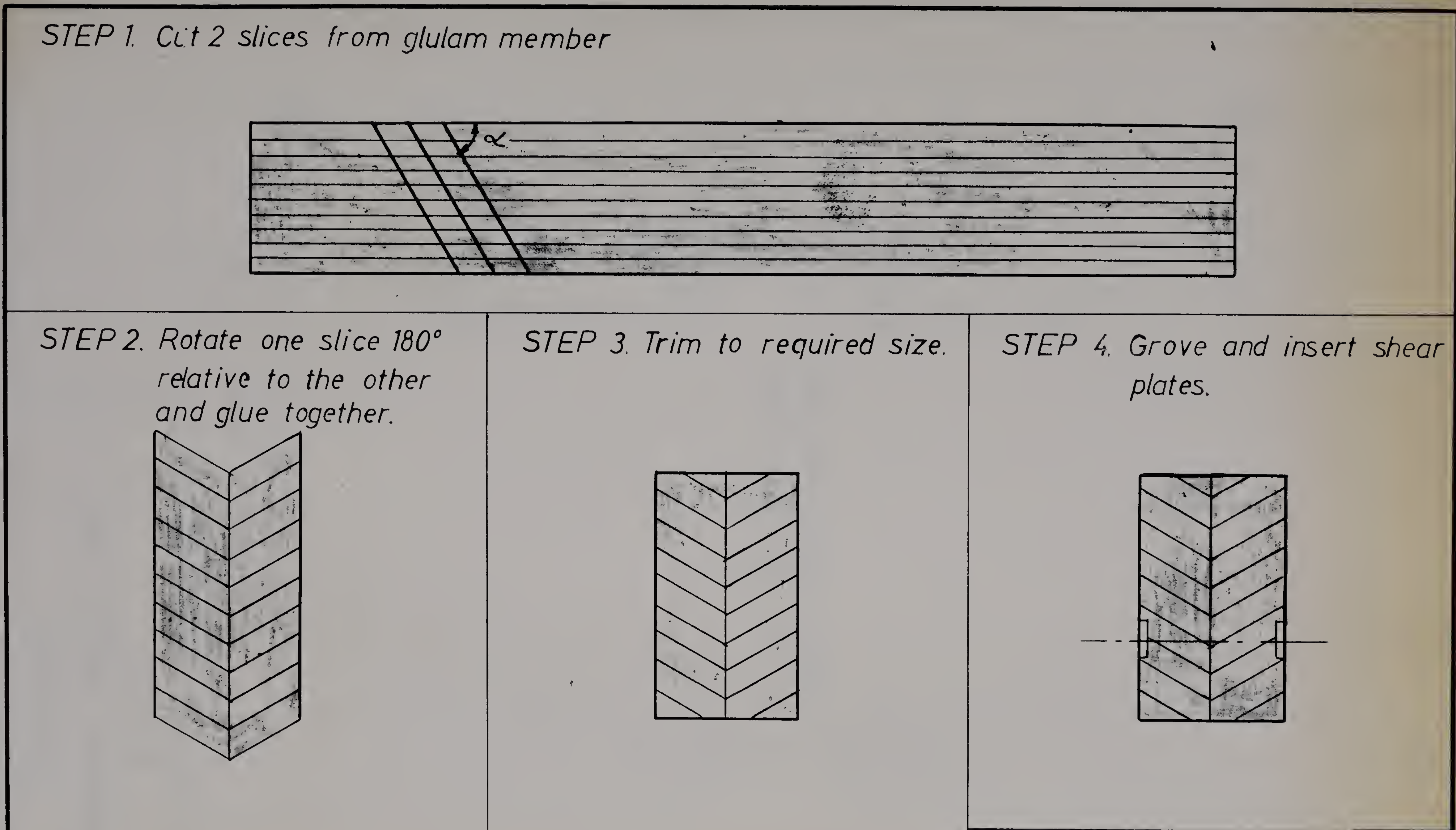


Fig. 3.2

SPECIMEN FABRICATION

Not to scale

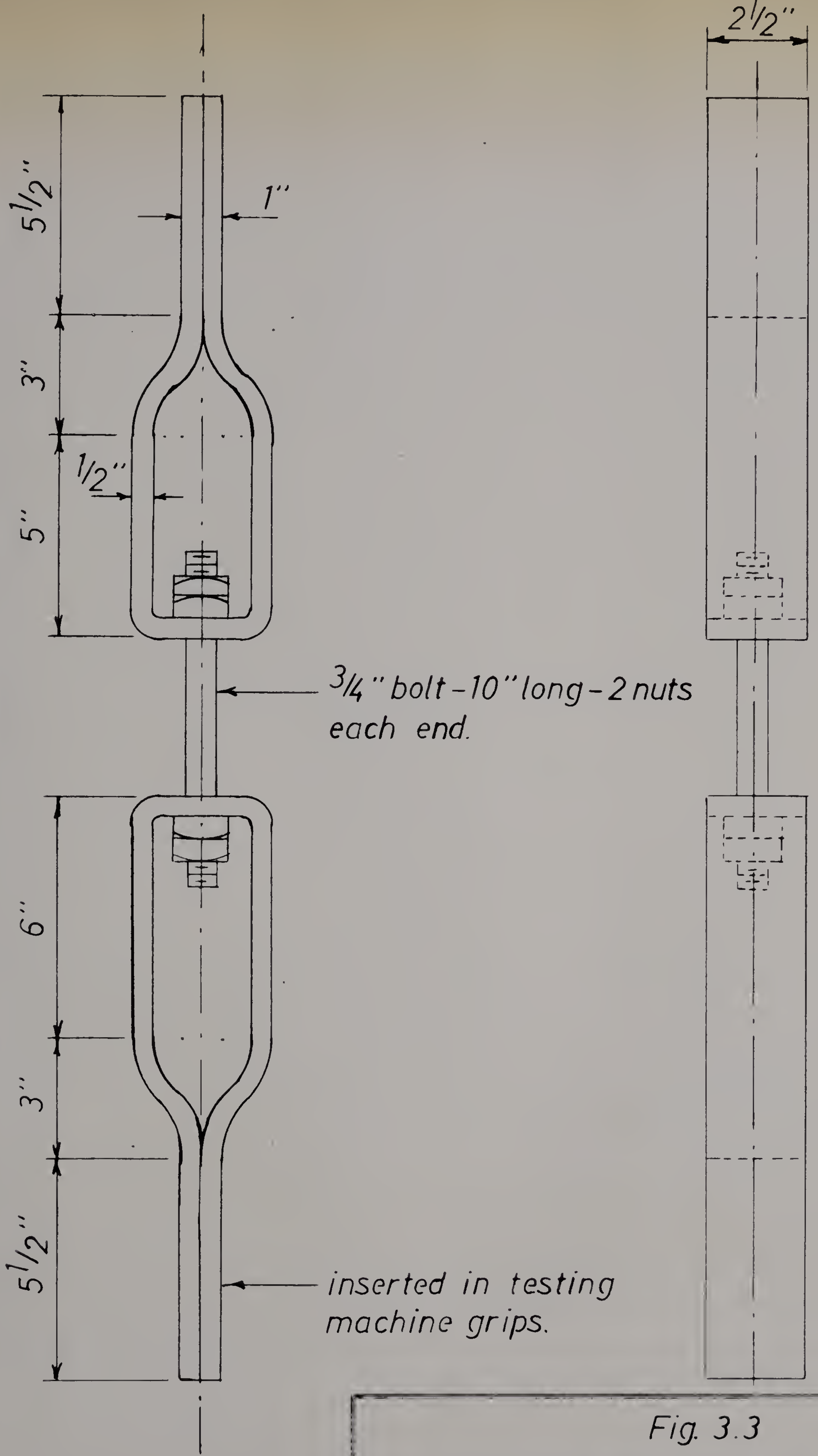


Fig. 3.3

BOLT TESTING APPARATUS

Scale: 1" = 4"

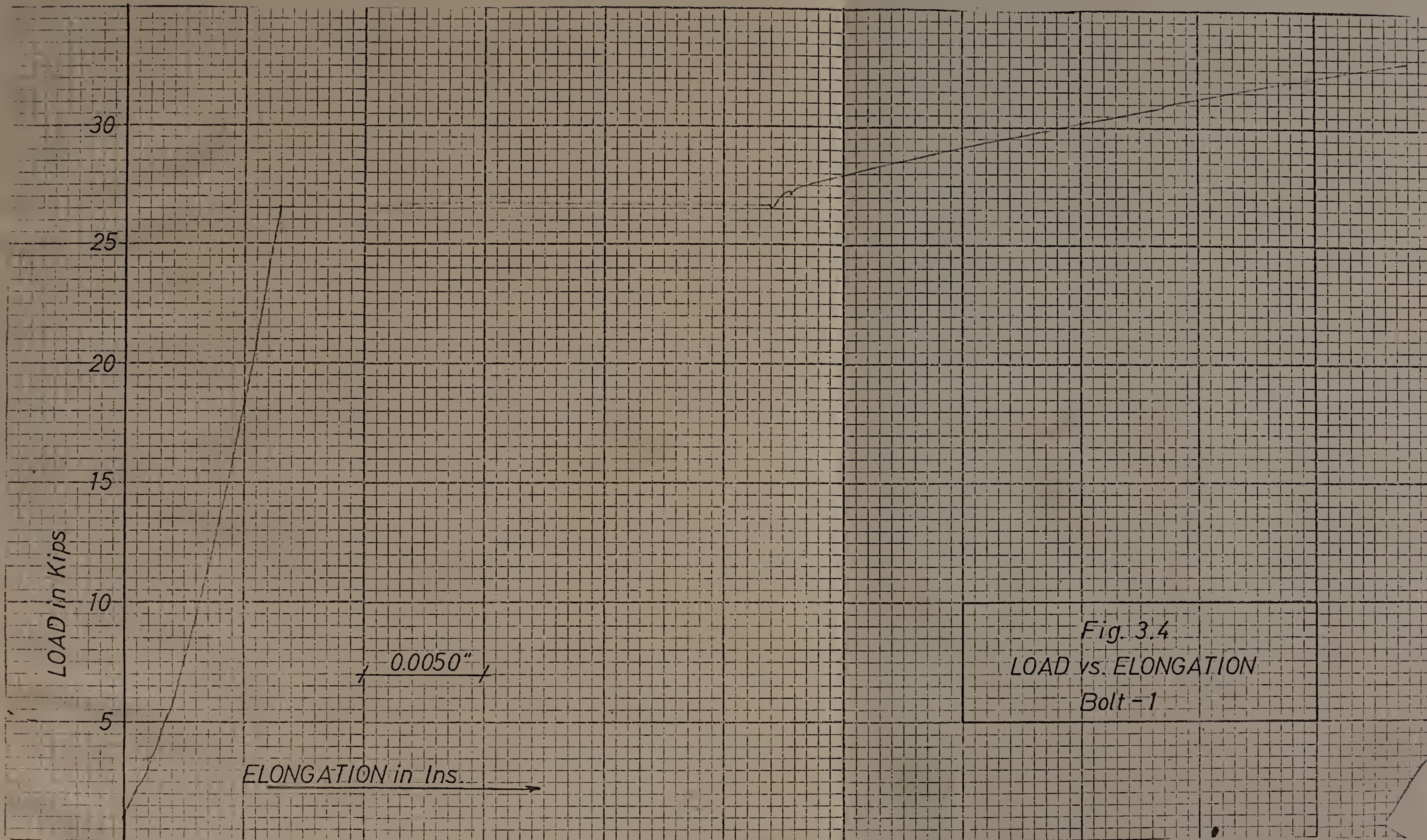


Fig. 3.4
LOAD vs. ELONGATION
Bolt -1

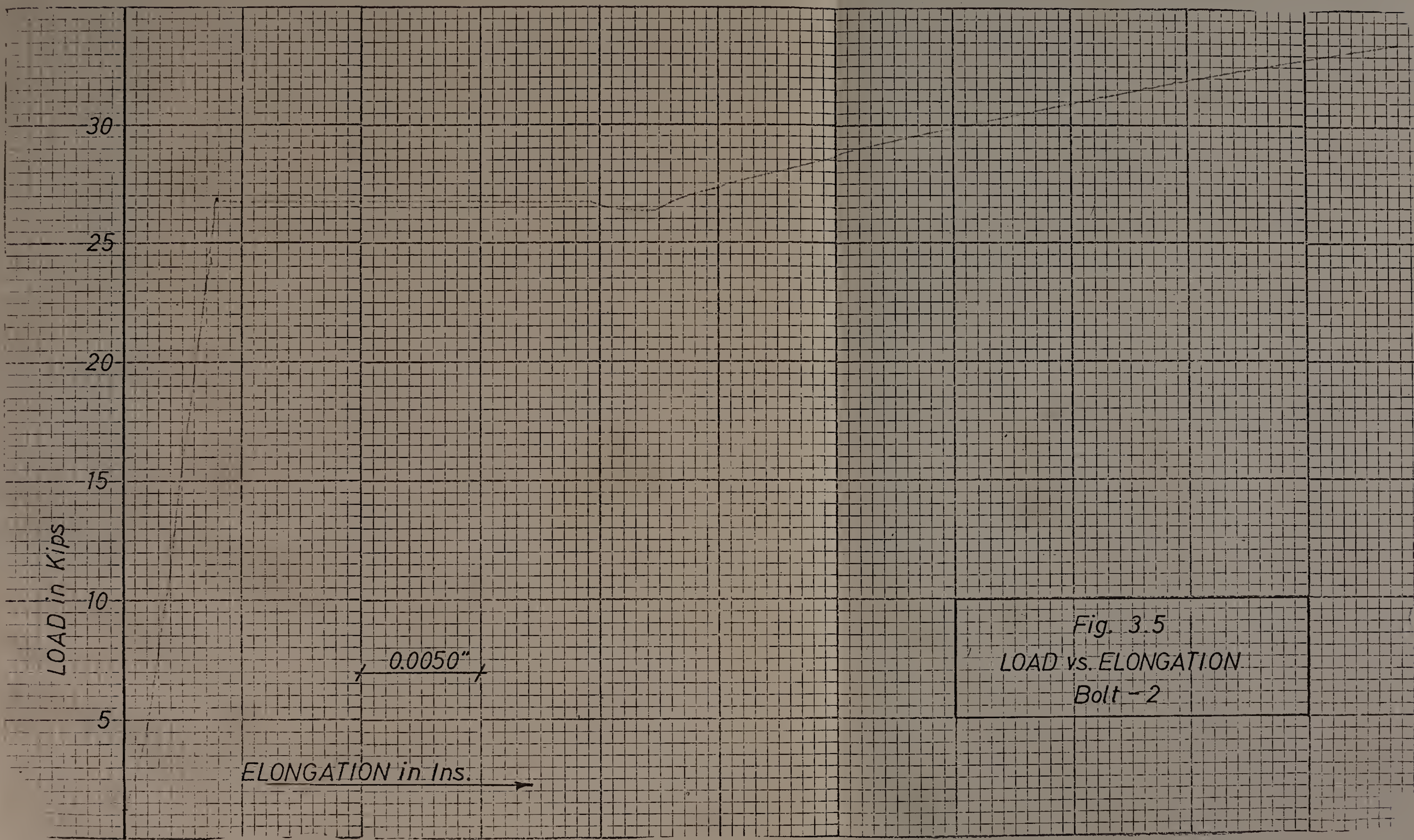


Fig. 3.5
LOAD vs. ELONGATION
Bolt – 2

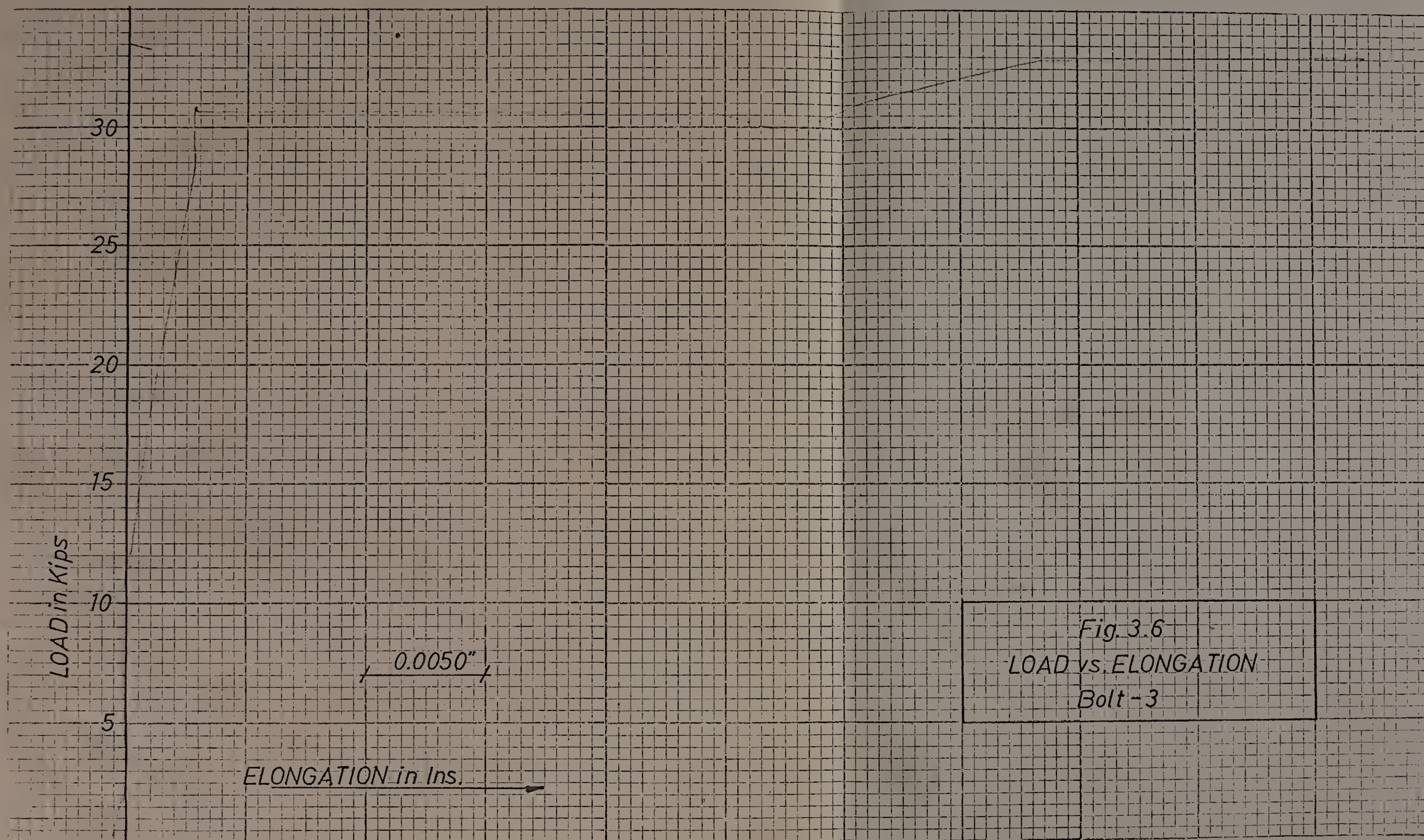


Fig. 3.6
LOAD vs. ELONGATION
Bolt - 3

TABLE III-1 TENSION TEST RESULTS FOR BOLTS

Specimen	(1) Diameter in inches	(2) Area in sq. ins.	(3) Yield Load in lbs	(4) Yield Stress in psi	(5) Ultimate Load in lbs.	(6) Ultimate Stess in psi	(7) Initial Gage in	(8) Final Gage in	(9) Elongation %
(1)	.753	.446	26,500	59,500	34,050	76,400	2.00	2.07	3.5
(2)	.750	.442	26,750	60,500	34,500	78,200	2.00	2.12	6.0
(3)	.750	.442	30,800	69,700	39,150	88,600	2.00	2.07	3.5

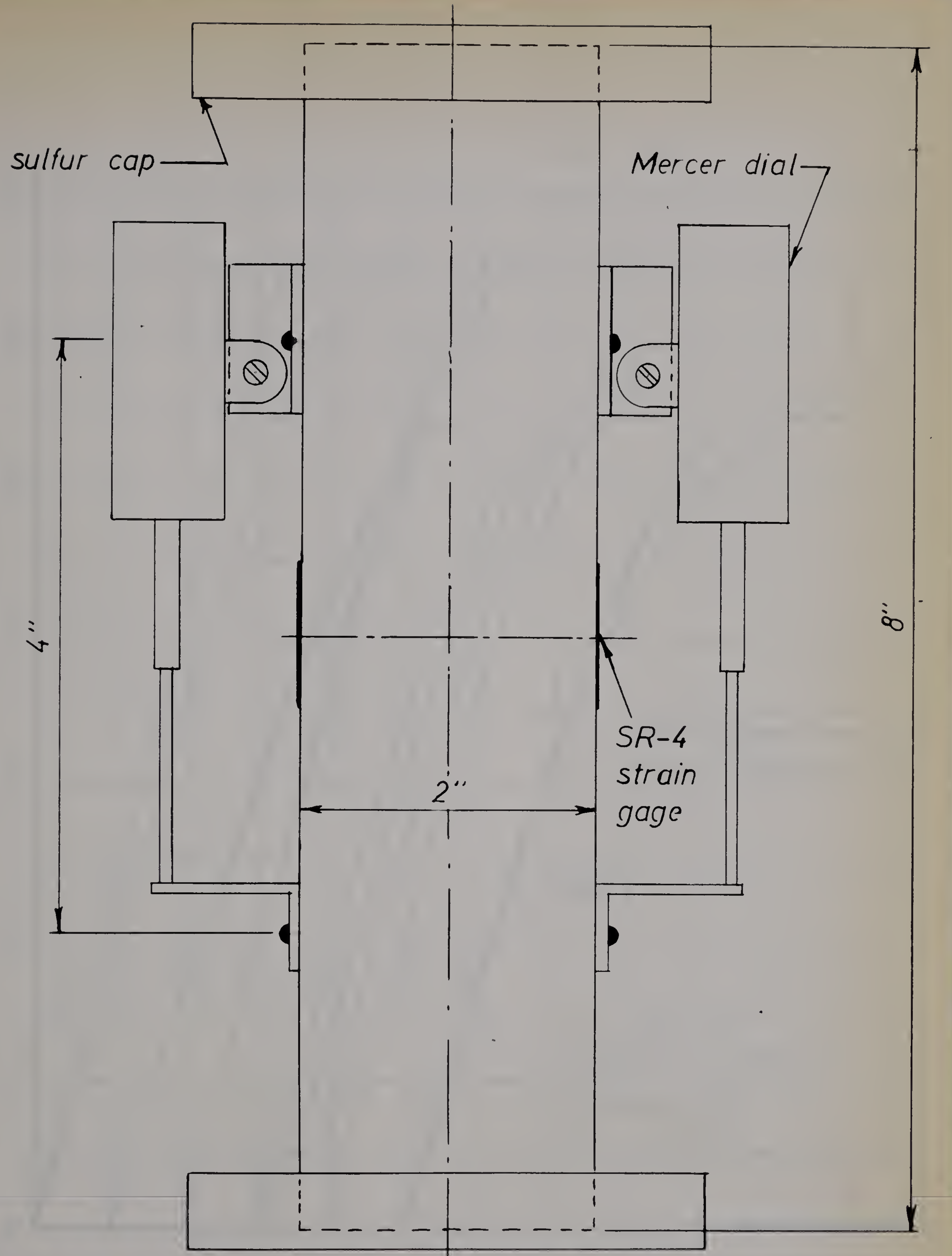


Fig. 3.7
TEST APPARATUS FOR SMALL DOUGLAS FIR COMPRESSION SPECIMENS
Full scale

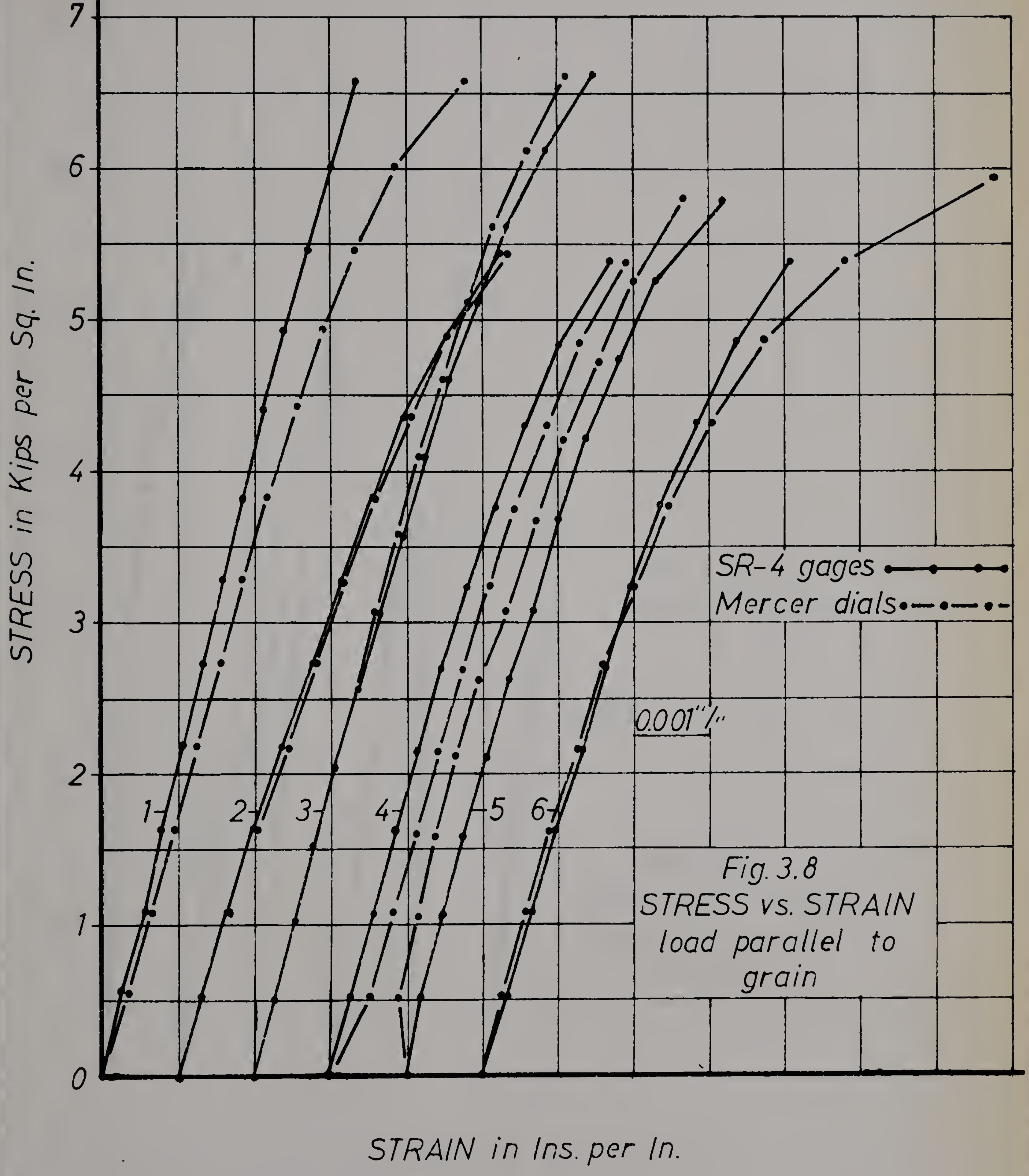
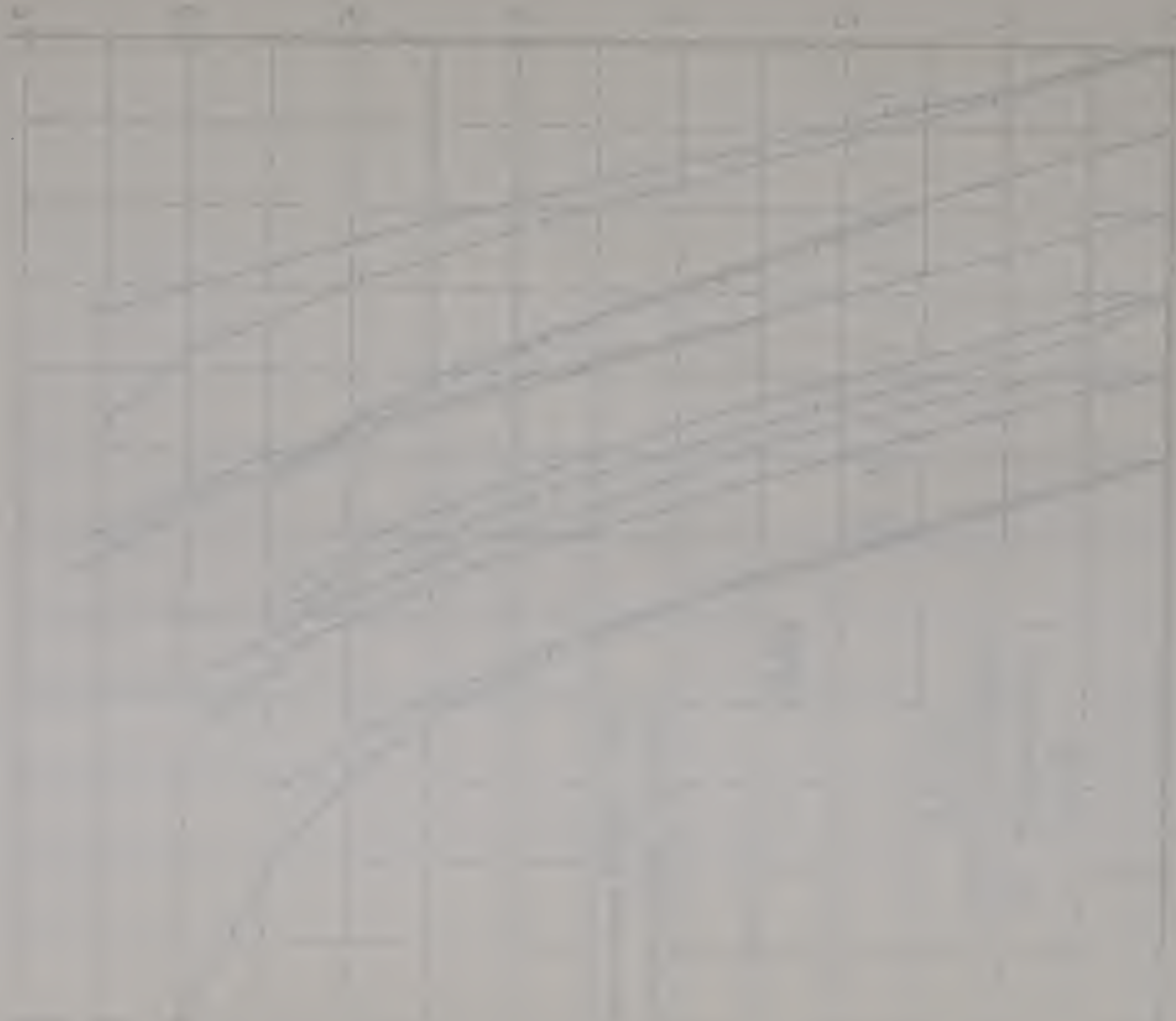


Fig. 3.8
STRESS vs. STRAIN
load parallel to
grain



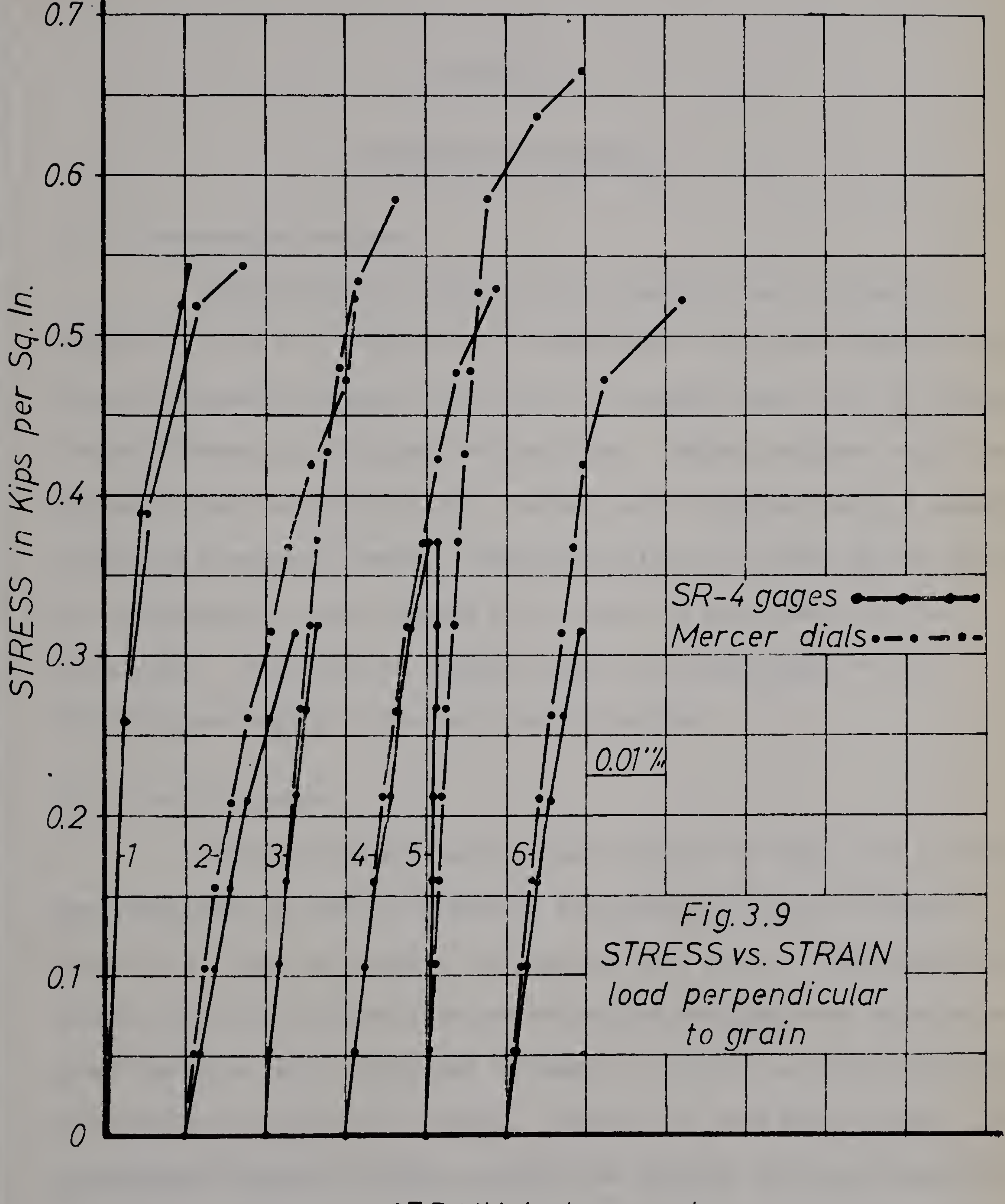
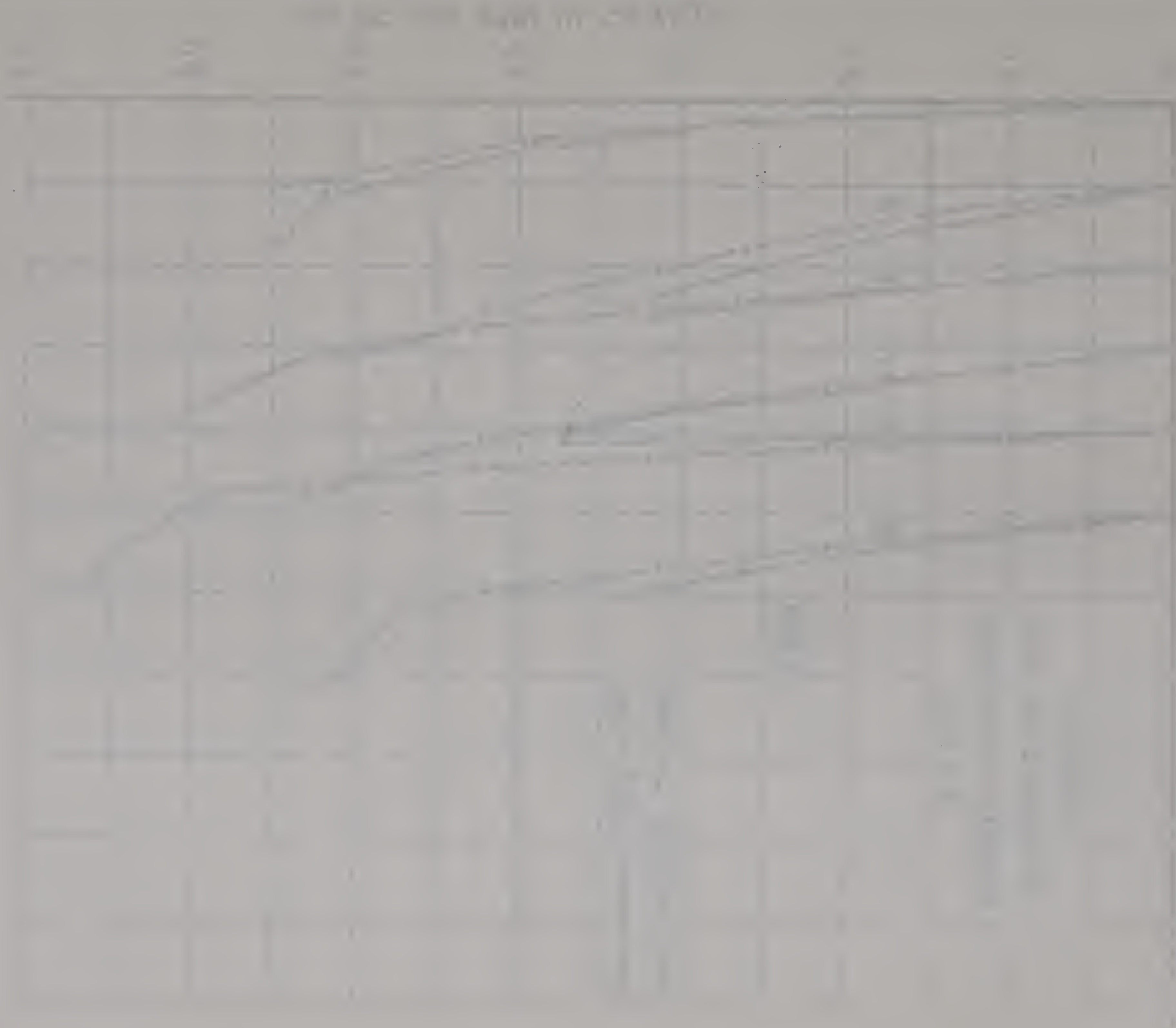


Fig. 3.9
STRESS vs. STRAIN
load perpendicular
to grain



CHAPTER IV

EXPERIMENTAL PROCEDURE

4.1 Preparation for Test

The specimen was placed in the loading frame as shown in Figures 4.1 and 4.2. Three inch by one-eighth inch spacer washers were inserted between the shear plates and the loading frame so as to prevent contact between the specimen and the frame. Washers and nuts were then placed on each end of the bolt. The nuts were tightened using a moderate torque on a ten-inch wrench. The brackets from the centre of the specimen to the deflection dials mounted on the front of the frame were then positioned. The frame was centered under the loading head of the 200,000 pound capacity Universal Testing Machine.

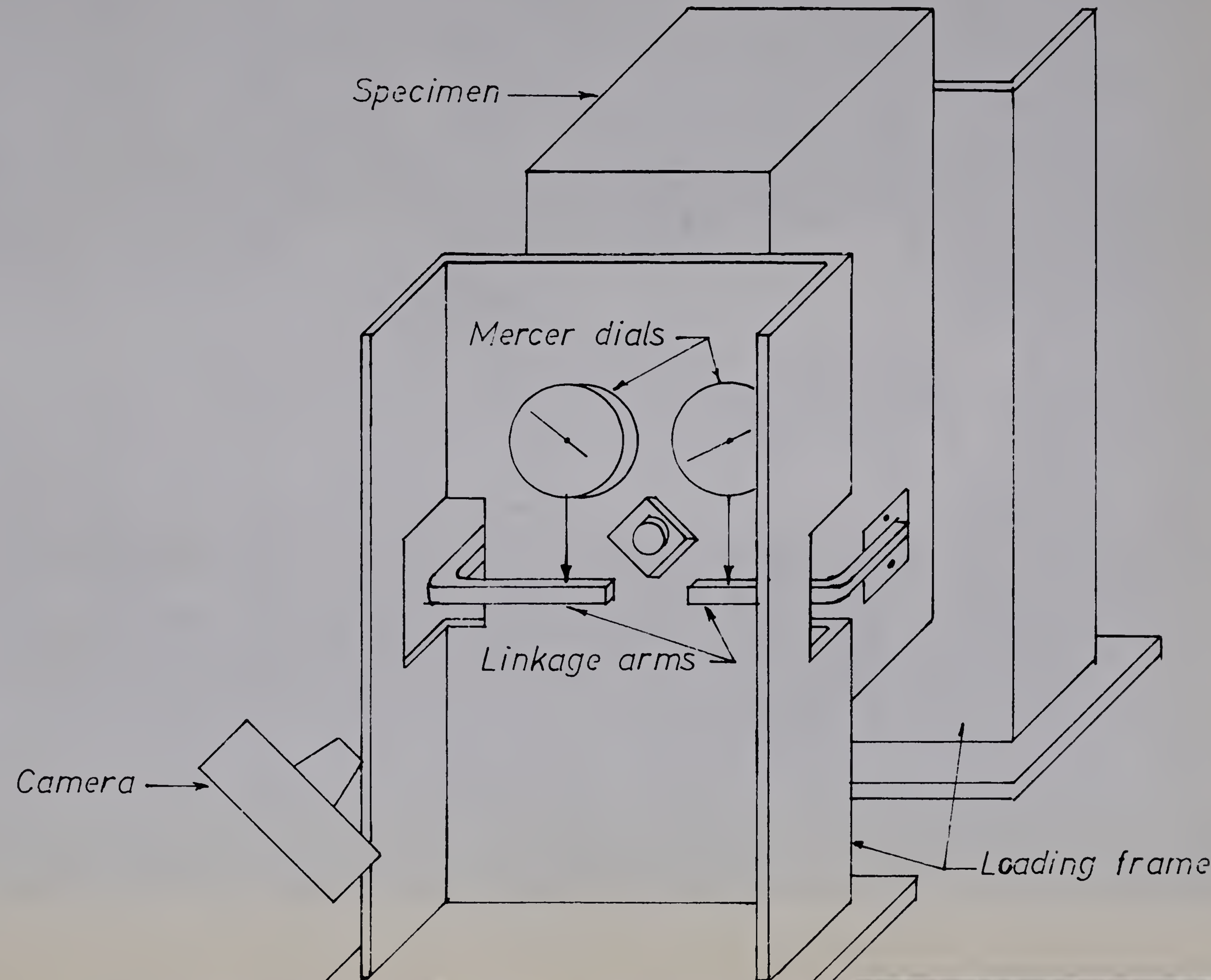
4.2 Test Procedure.

A thirty-five millimeter camera taking 1/2 frame size pictures was positioned so that it focused on the deflection dials as shown in Figure 4.3. Load was applied continuously at a rate of 5,000 pounds per minute up to the ultimate load and deflection readings were taken photographically at each 1,000 pound increment. The film was later developed and placed in a micro-film viewer. The data was read and recorded. The photographic method of taking readings was employed in order that greater accuracy in dial readings might be realized, that a permanent record of the data would be available, and since readings were required every 12 seconds this proved the most effective procedure.

4.3 Moisture Content and Specific Gravity Determination.

Three samples from each group of six specimens were analyzed for moisture content and specific gravity. These samples were approximately two inch cubes taken from the centre portion of the specimen just above the bolt. The samples were weighed, dried in an oven at 105°C for twenty-four hours, re-weighed, coated with paraffin and then weighed again. The volume of the specimen was obtained by the mercury displacement method. The moisture content was based on the dry weight of the sample. The specific gravity was based on the dry weight and dry volume of the sample.

Fig. 4.1 LOADING FRAME WITH SPECIMEN READY FOR LOAD TESTING



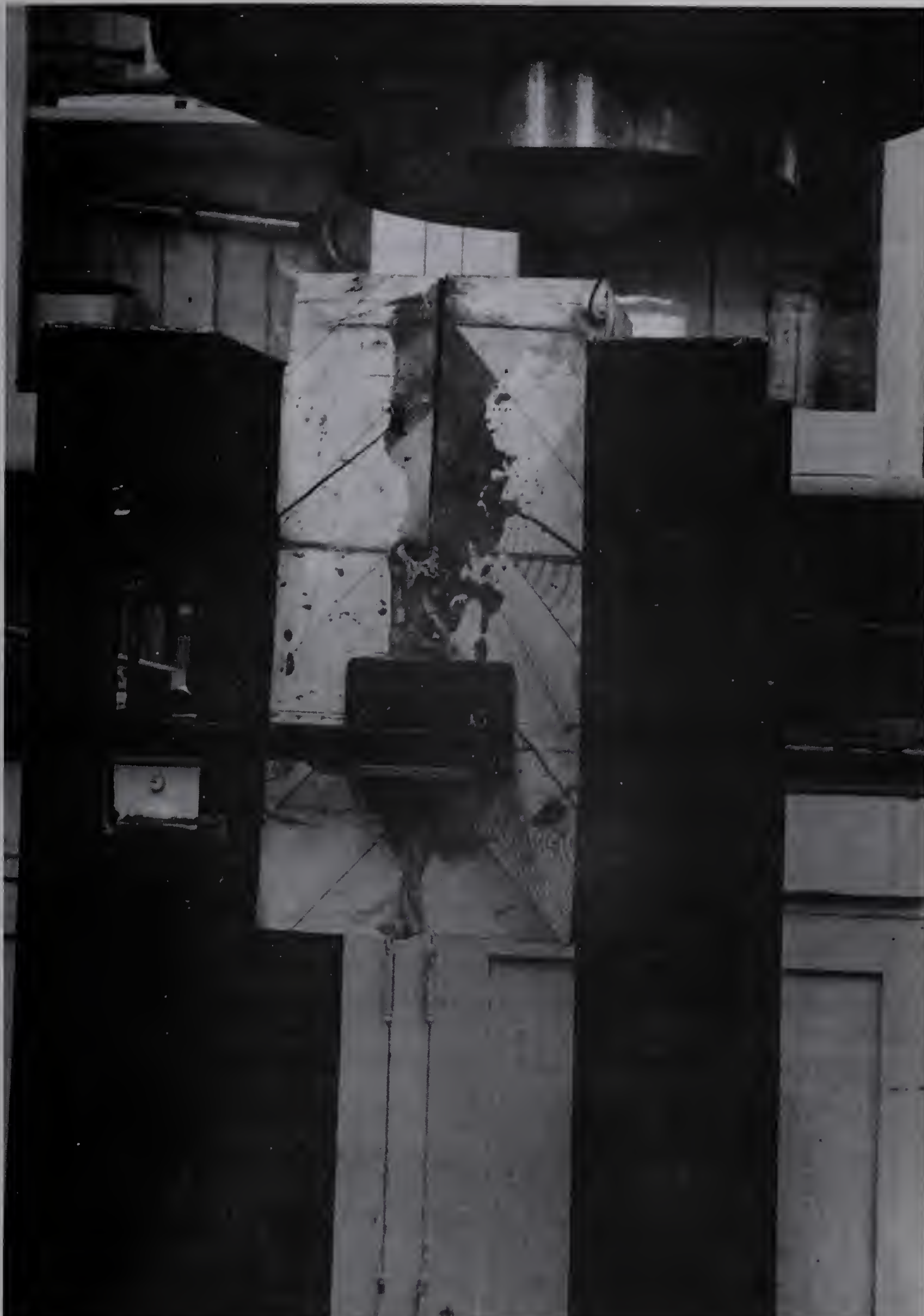


FIGURE 4.2

SIDE VIEW OF LOADING FRAME AND SPECIMEN AFTER LOAD TESTING.

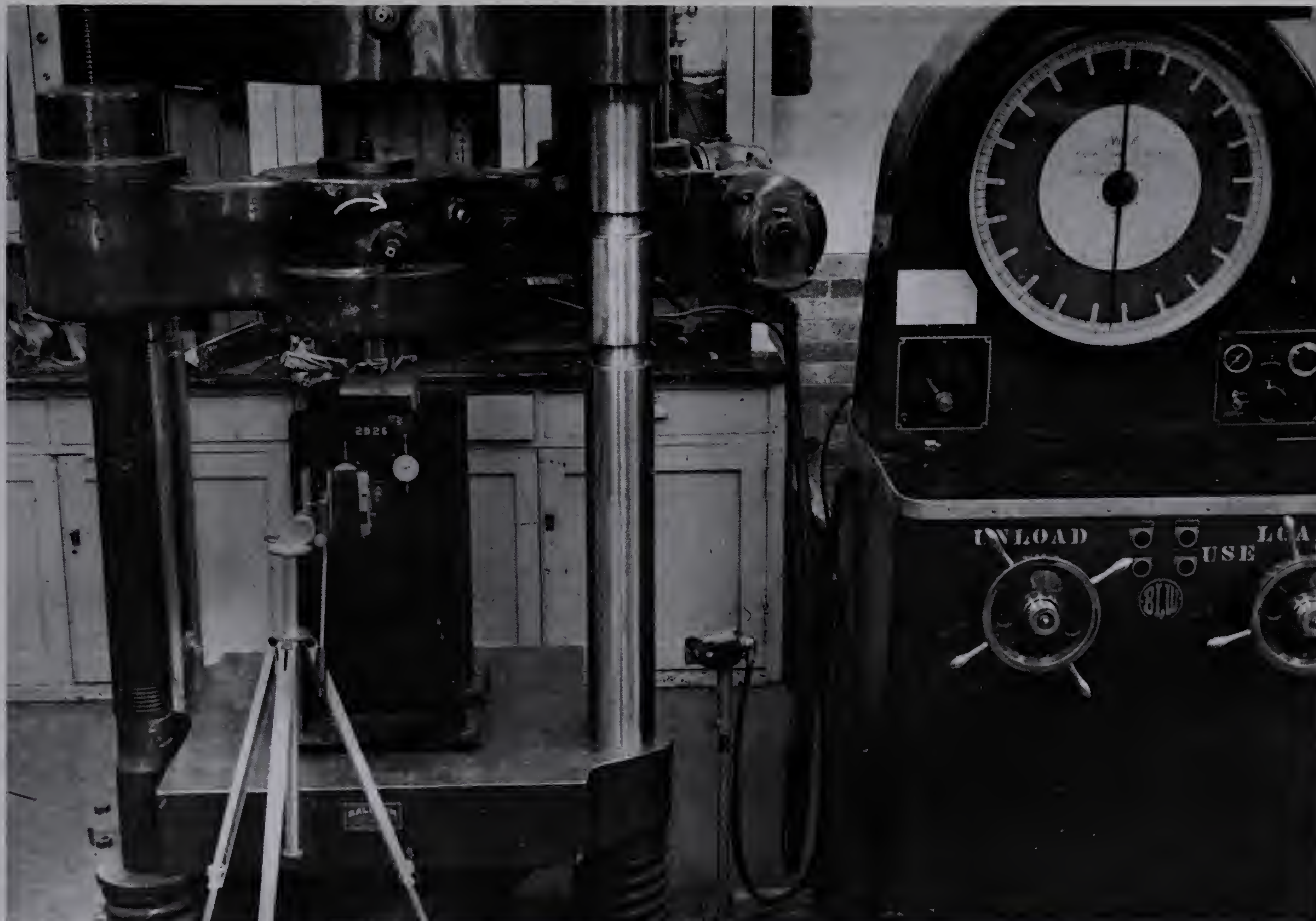


FIGURE 4.3

COMPLETE TESTING APPARATUS WITH CAMERA IN POSITION

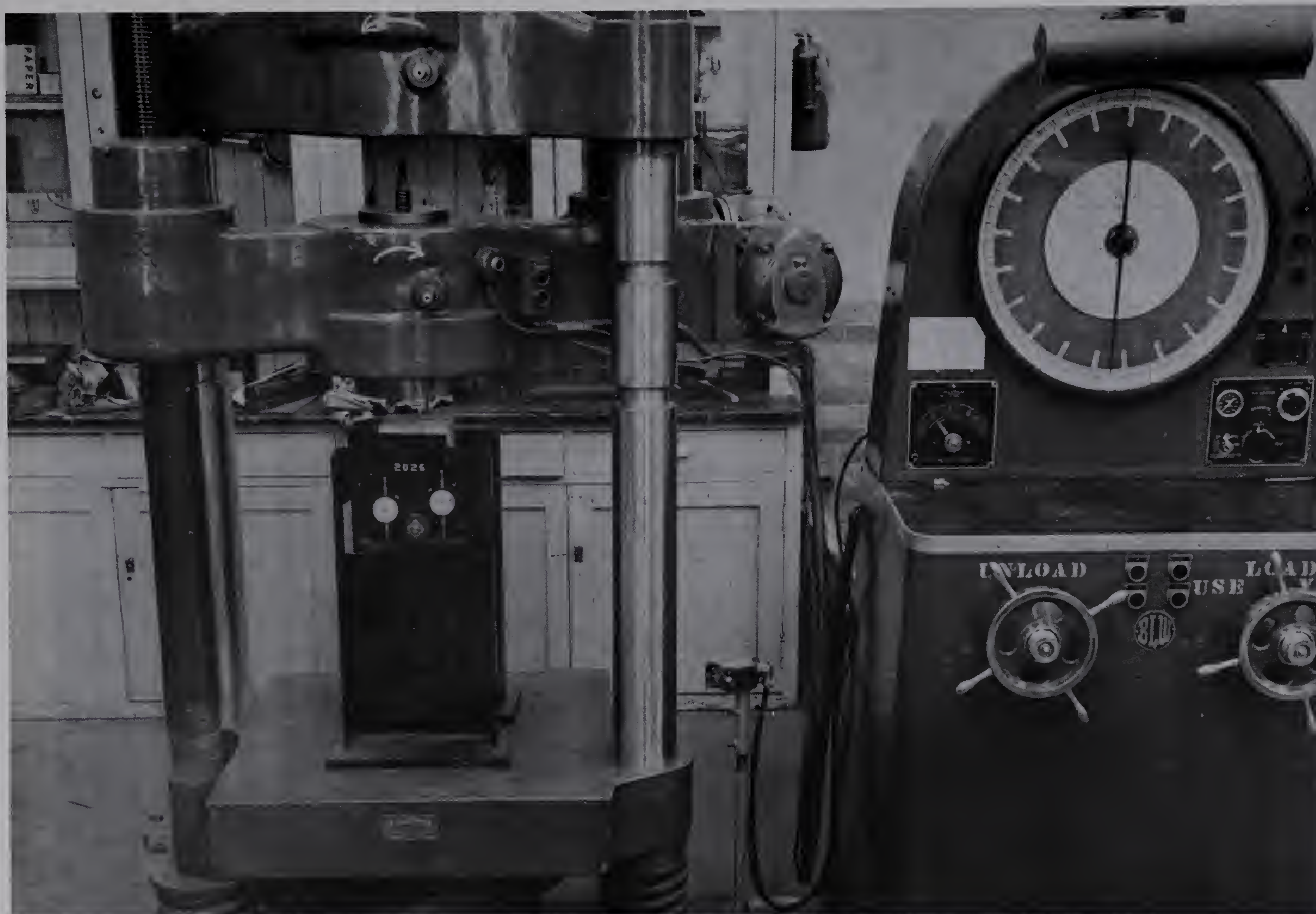


FIGURE 4.4

COMPLETE TESTING APPARATUS WITH CAMERA REMOVED

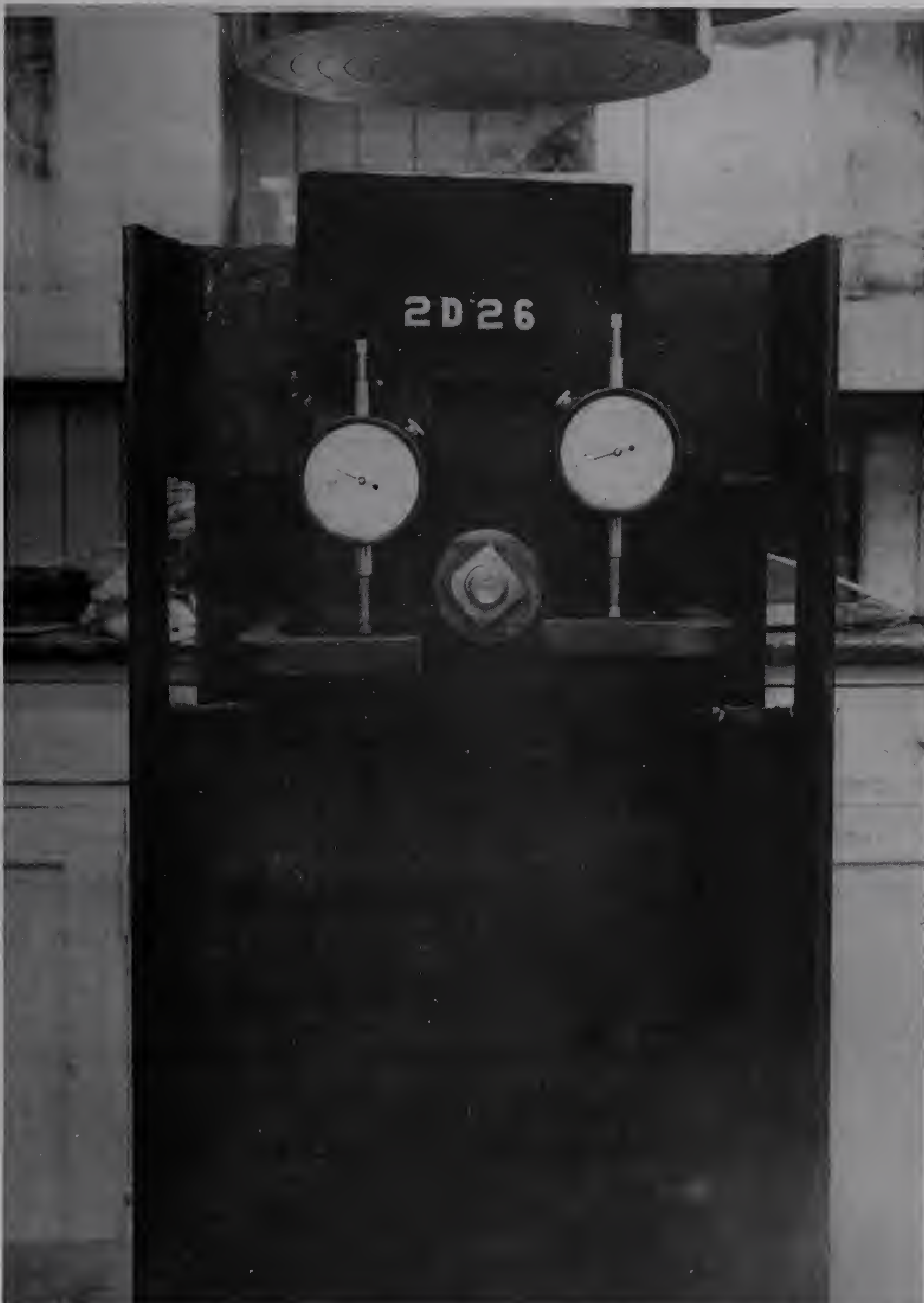


FIGURE 4.5
CLOSE-UP OF LOADING FRAME SHOWING DEFLECTION GAGES

CHAPTER V

TEST RESULTS

Test results are presented as follows:

(1) Load vs Slip Curves. Figures 5.1 and 5.32.

(2) Load vs Grain Angle α. Figures 5.33 and 5.34.

(3) Load vs Load Angle Θ. Figure 5.35.

(4) Slope of Load-Slip Relationship vs Grain Angle α. Figure 5.36.

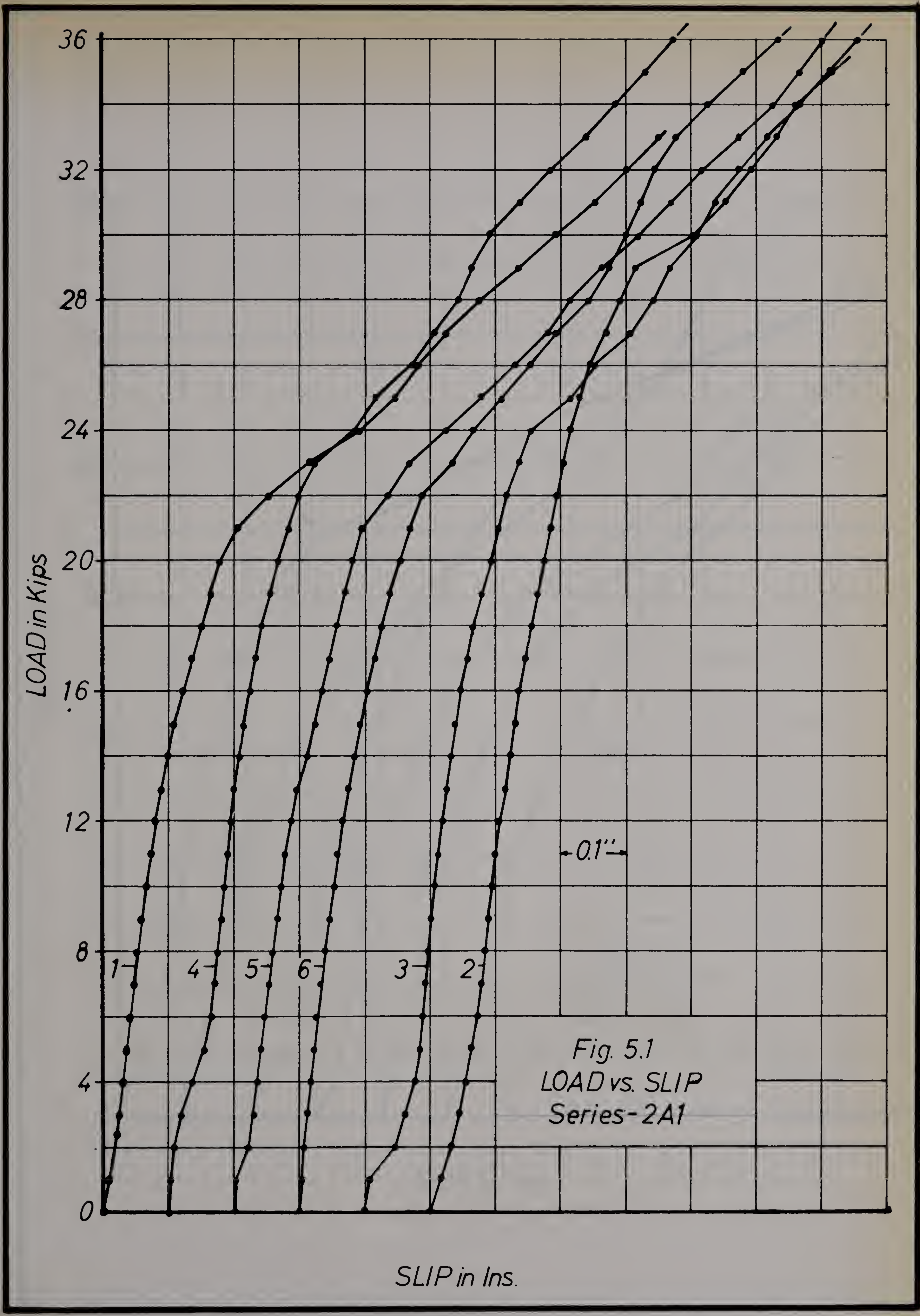
(5) Test Results in Tabular Form. Table V-1.

(6) Photographs of Specimens After Load Testing. Figures 5.37 to 5.40.

(7) Photographs of Shear Plates After Load Testing. Figures 5.41 and 5.42.

(8) Photographs of Bolts After Load Testing. Figure 5.43.

The original data sheets are kept on file at the Department of Civil Engineering, University of Alberta, Edmonton, Alberta. The photographs of all the specimens after load testing are included in the copy retained by the Department of Civil Engineering.


36
32
28
24
20
16
12
8
4
0
LOAD in Kips
SLIP in Ins.
1
4
5
6
3
2
0.1"
Fig. 5.1
LOAD vs. SLIP
Series-2A1

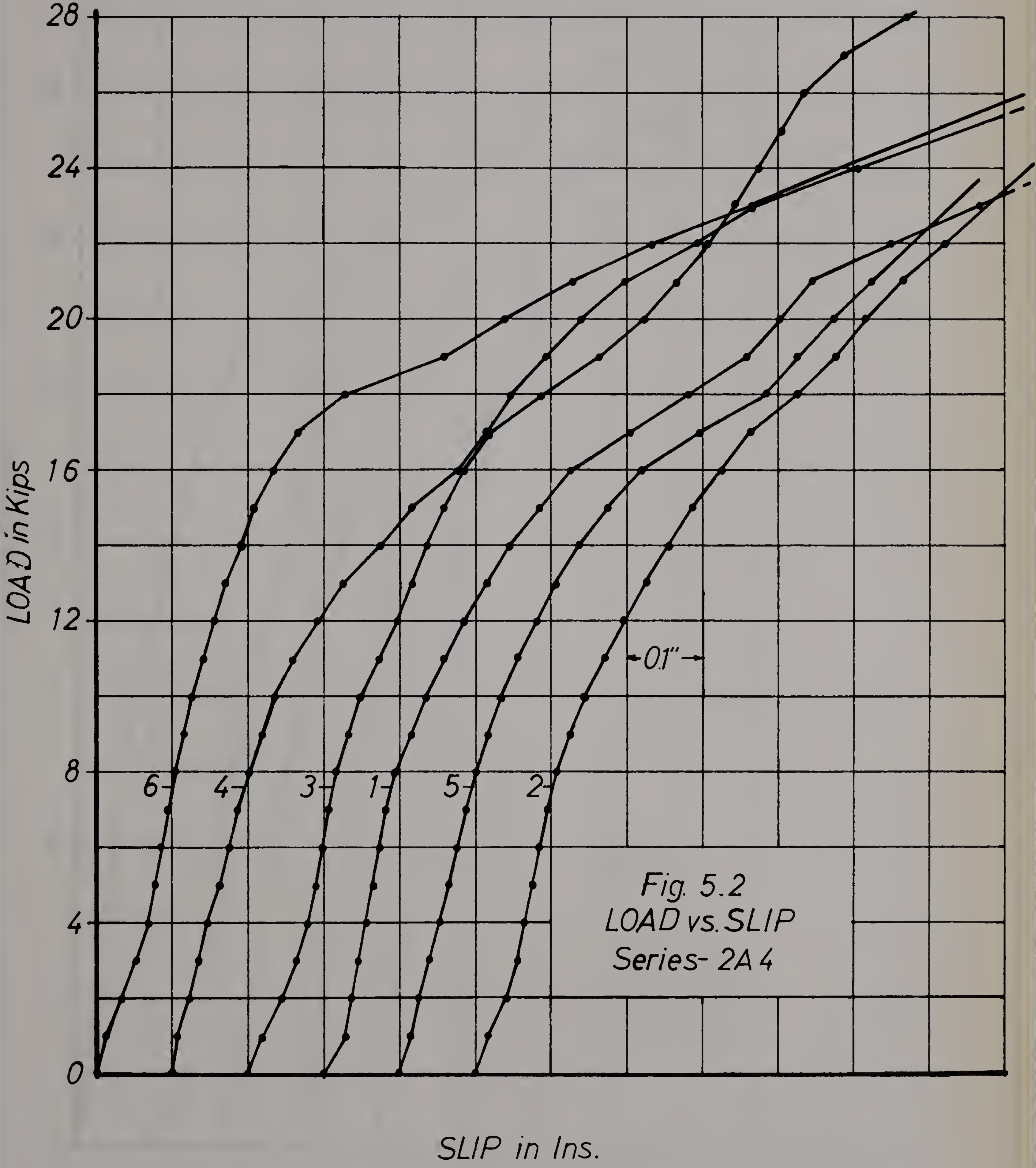
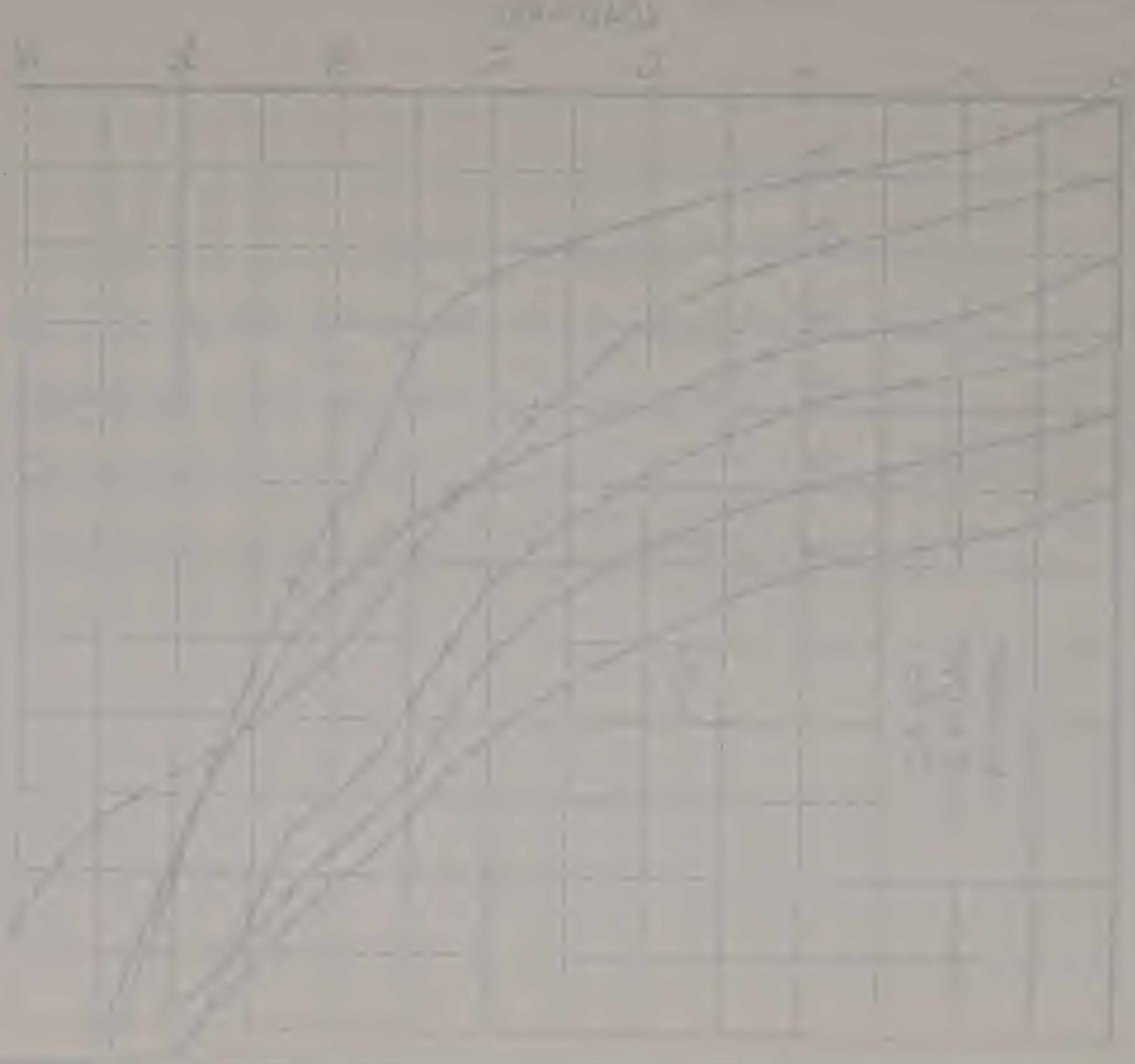


Fig. 5.2
LOAD vs. SLIP
Series- 2A 4



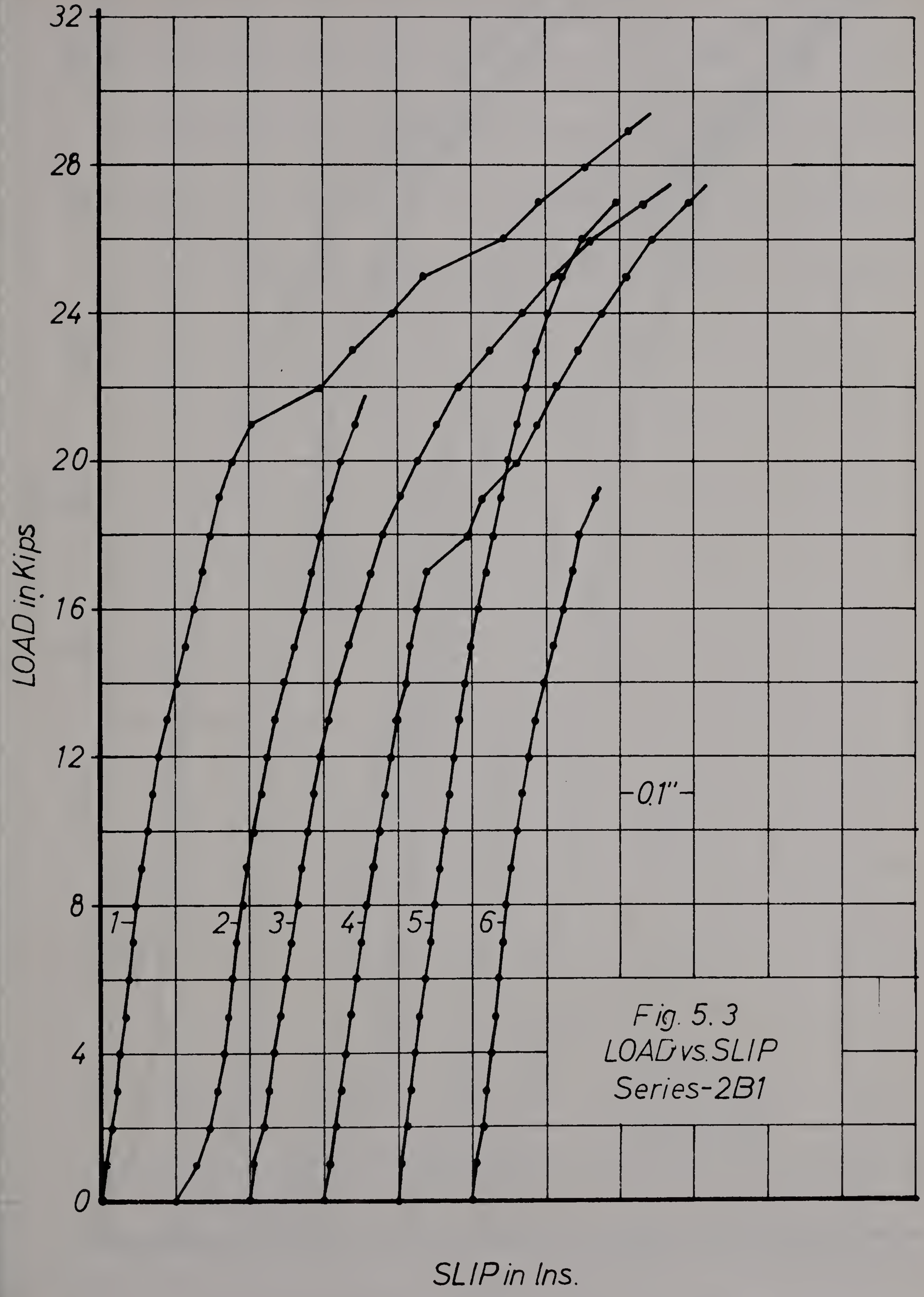
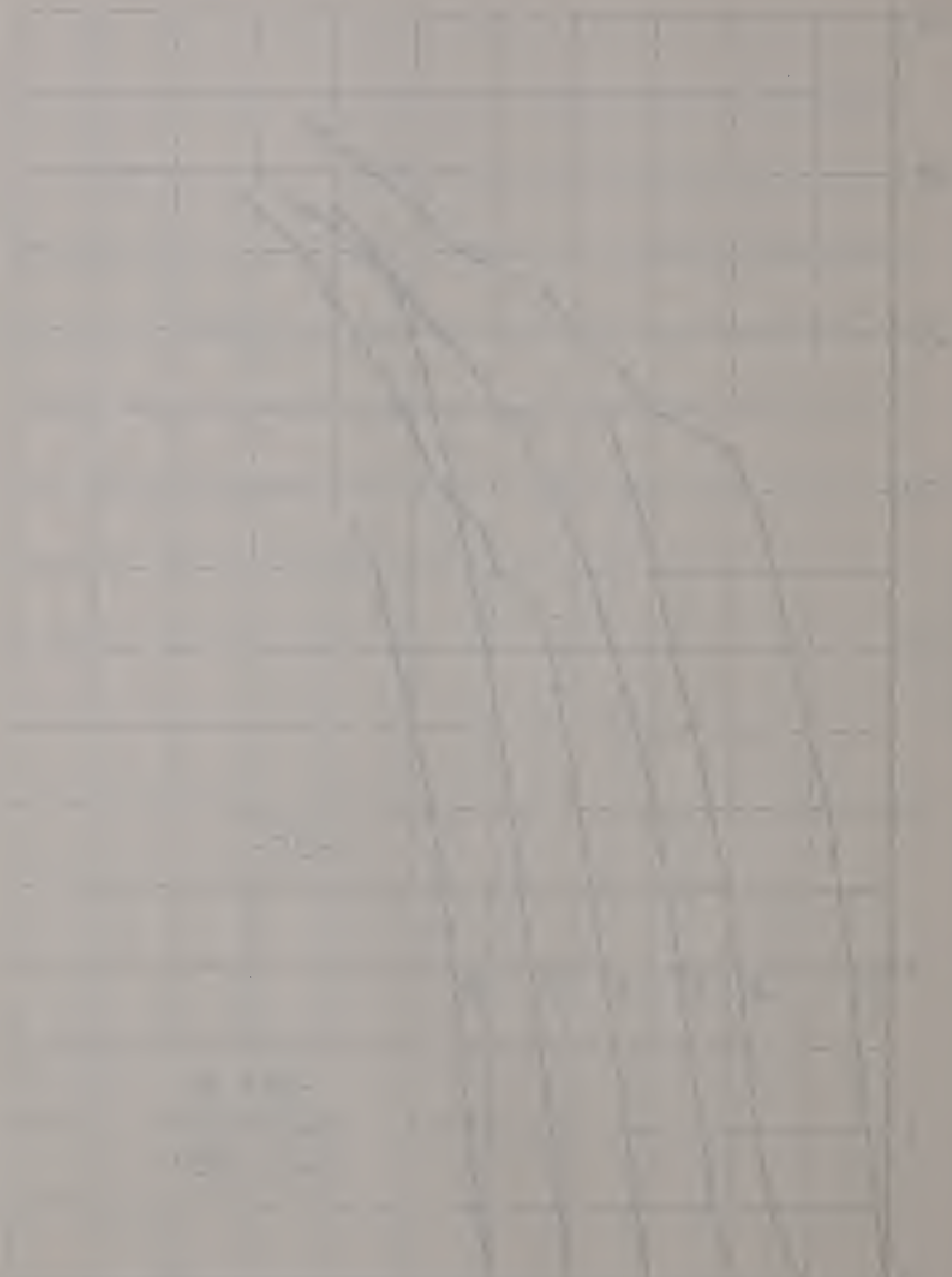


Fig. 5. 3
LOAD vs. SLIP
Series-2B1



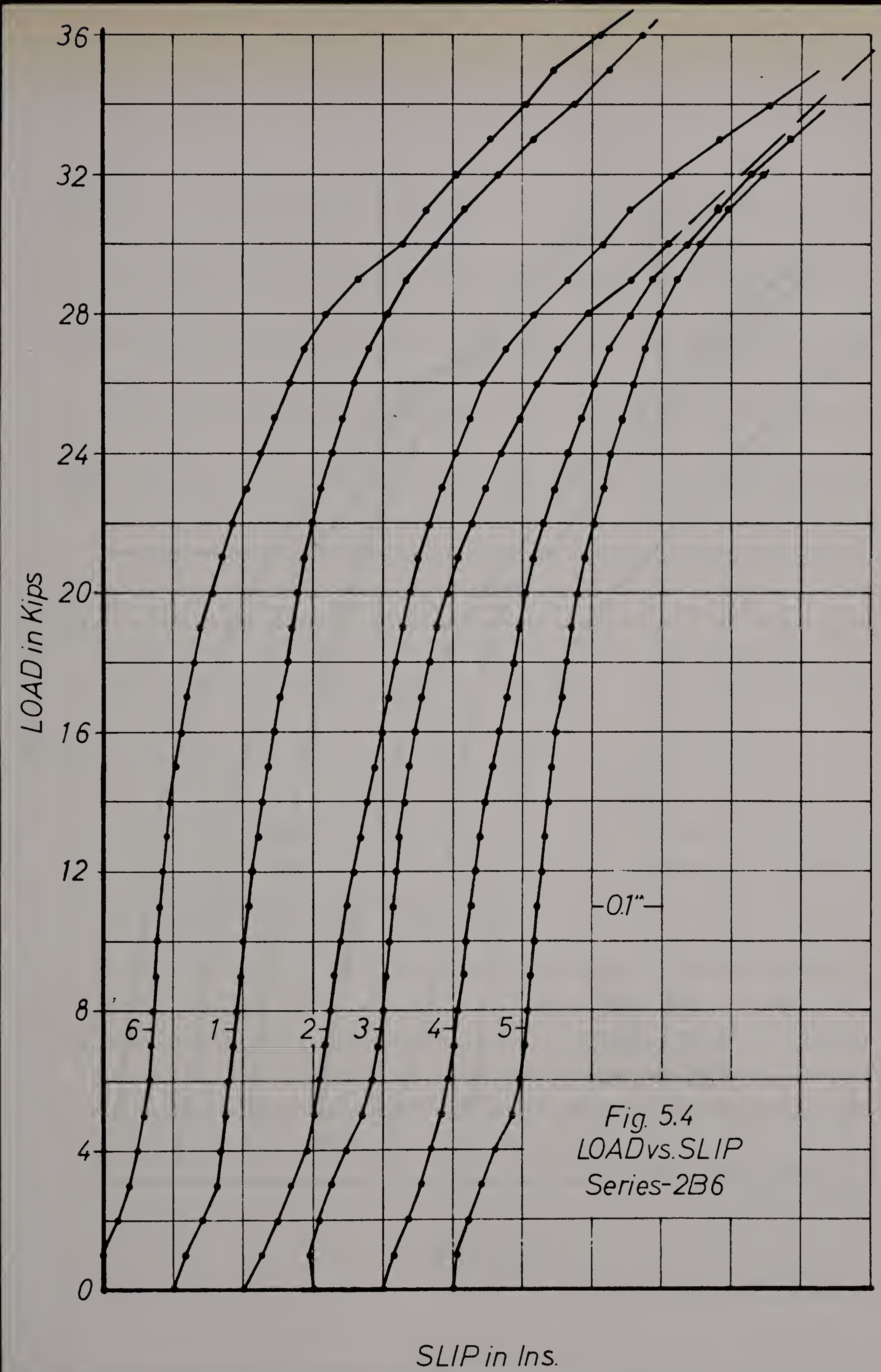


Fig. 5.4
LOAD vs. SLIP
Series-2B6

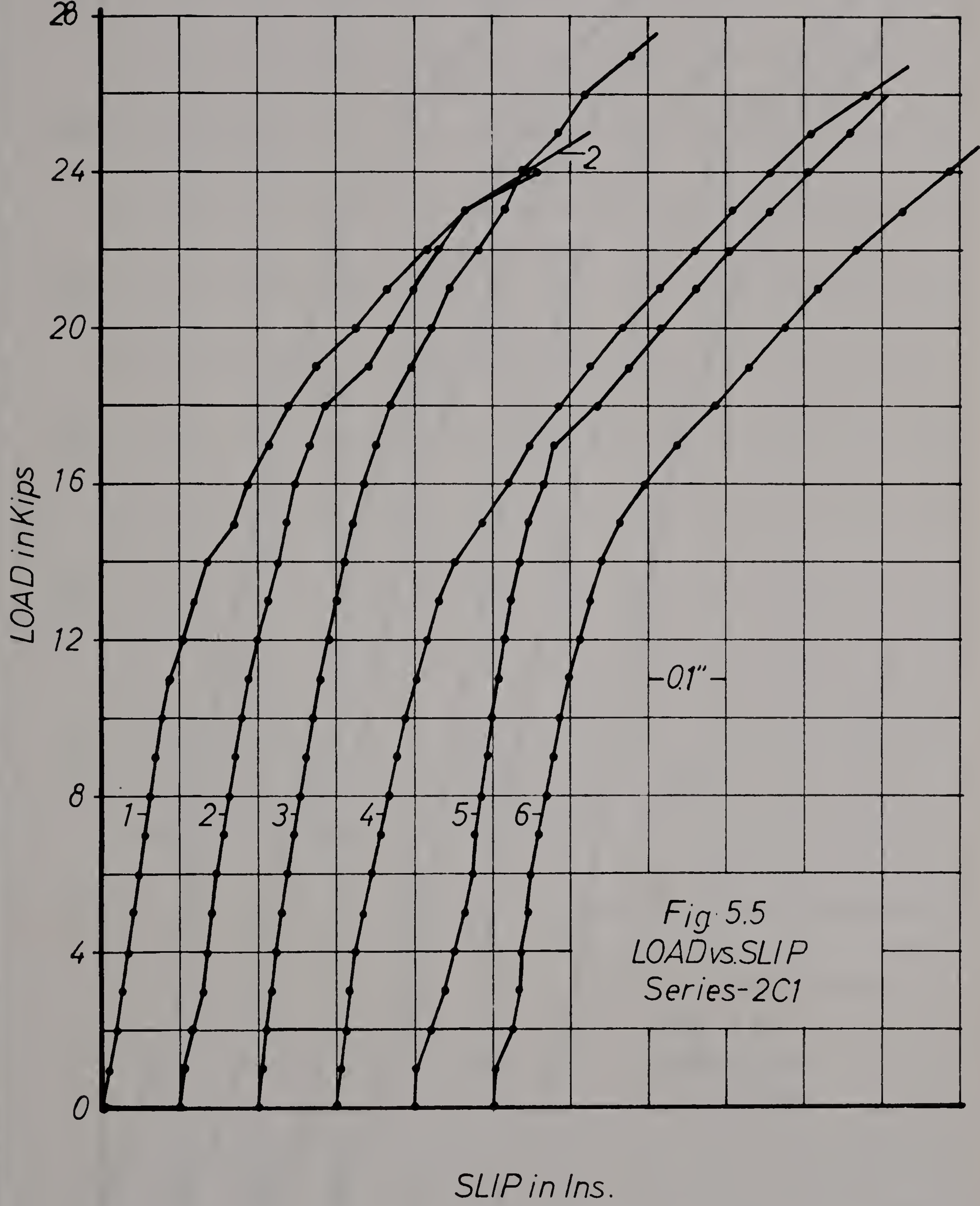


Fig. 5.5
LOAD vs. SLIP
Series-2C1

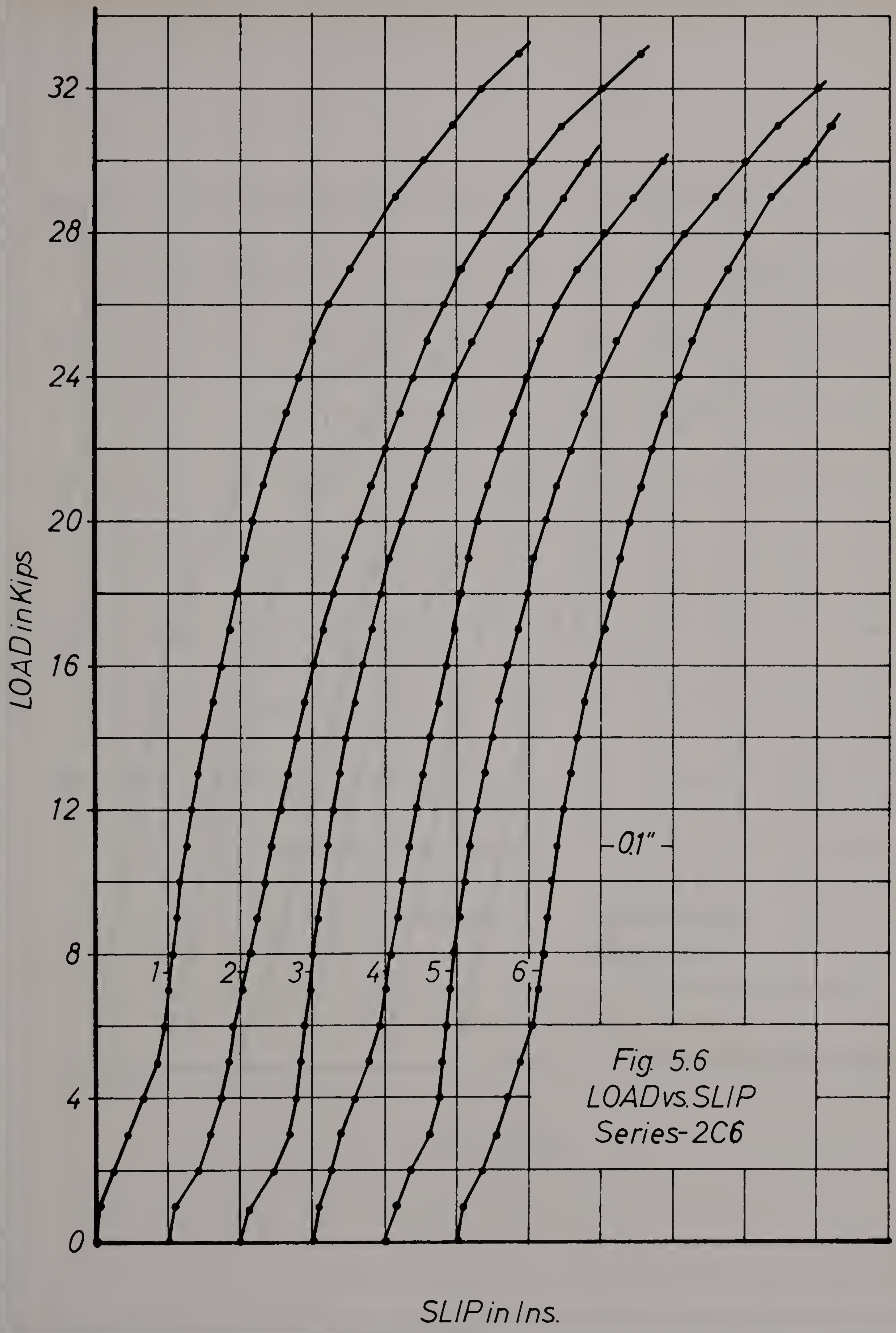
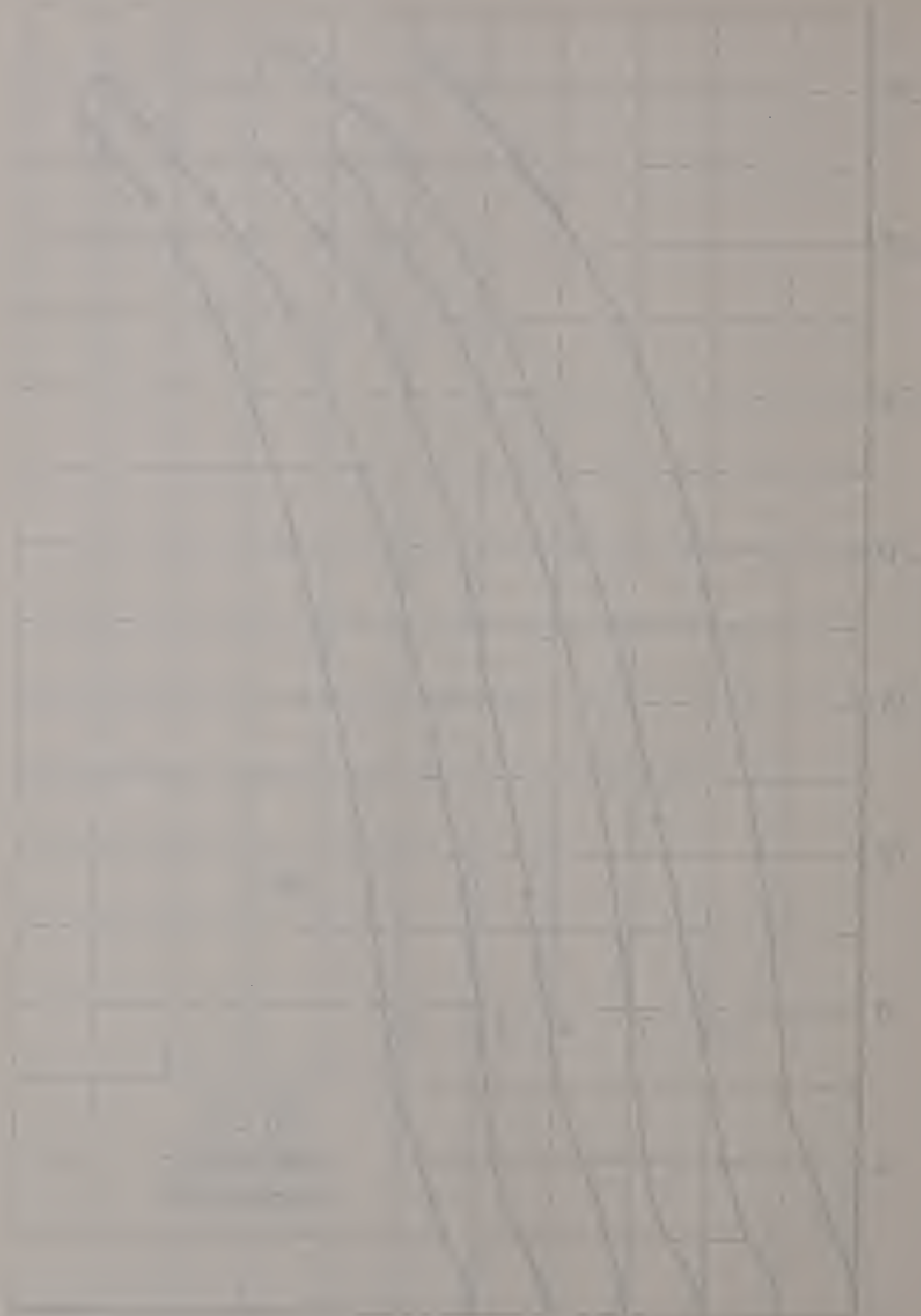


Fig. 5.6
LOAD vs. SLIP
Series-2C6



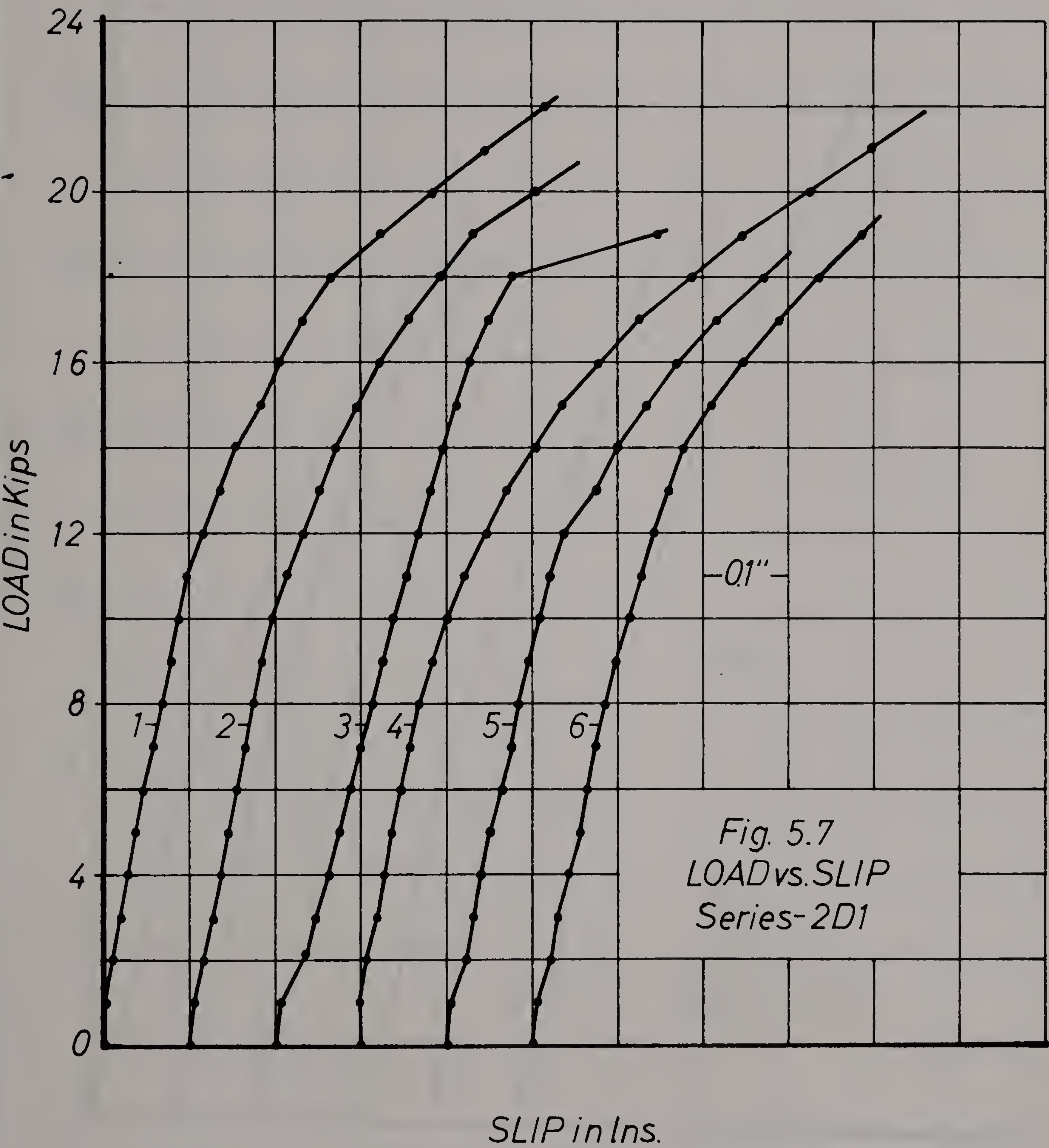
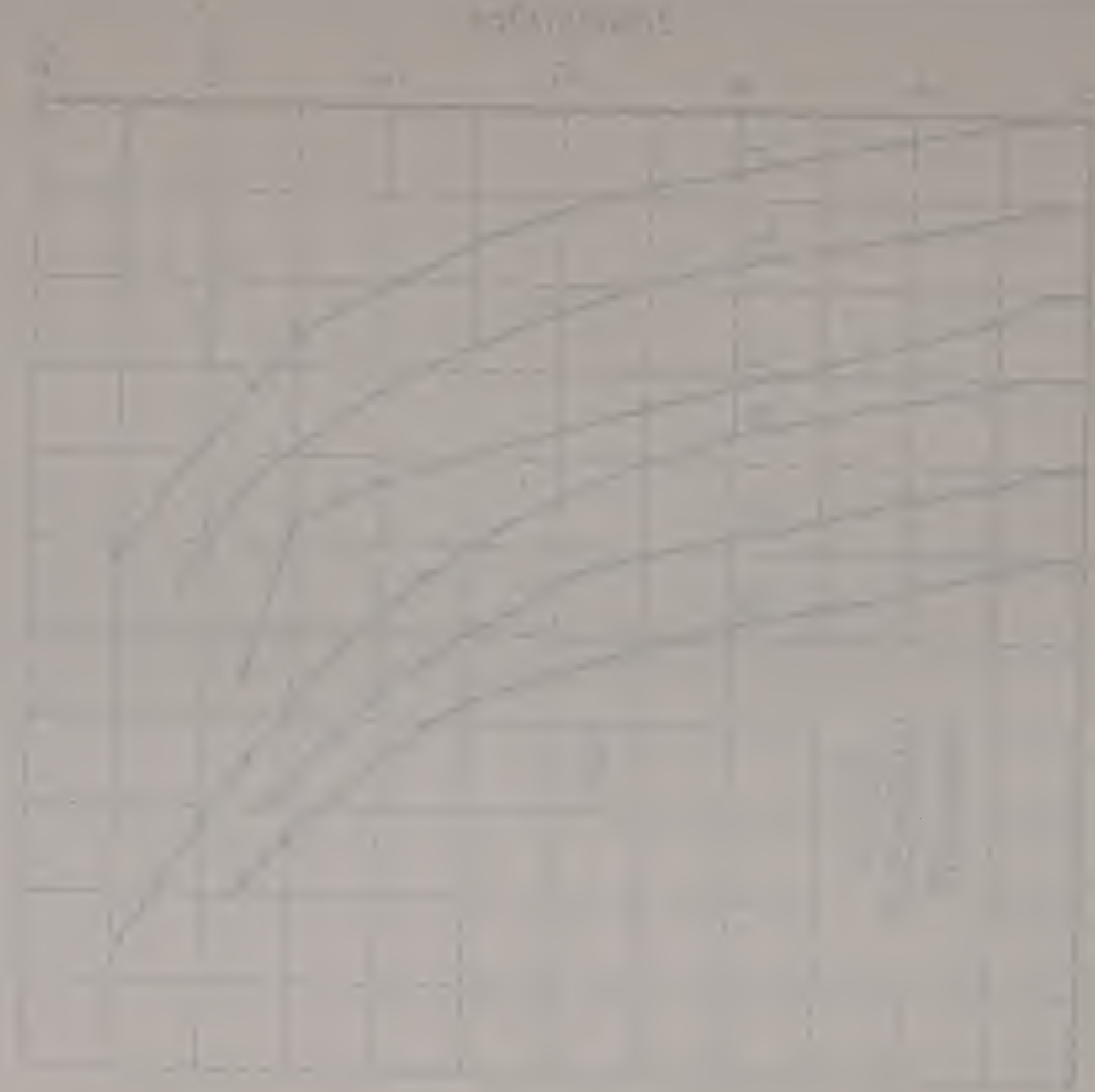


Fig. 5.7
LOAD vs. SLIP
Series-2D1



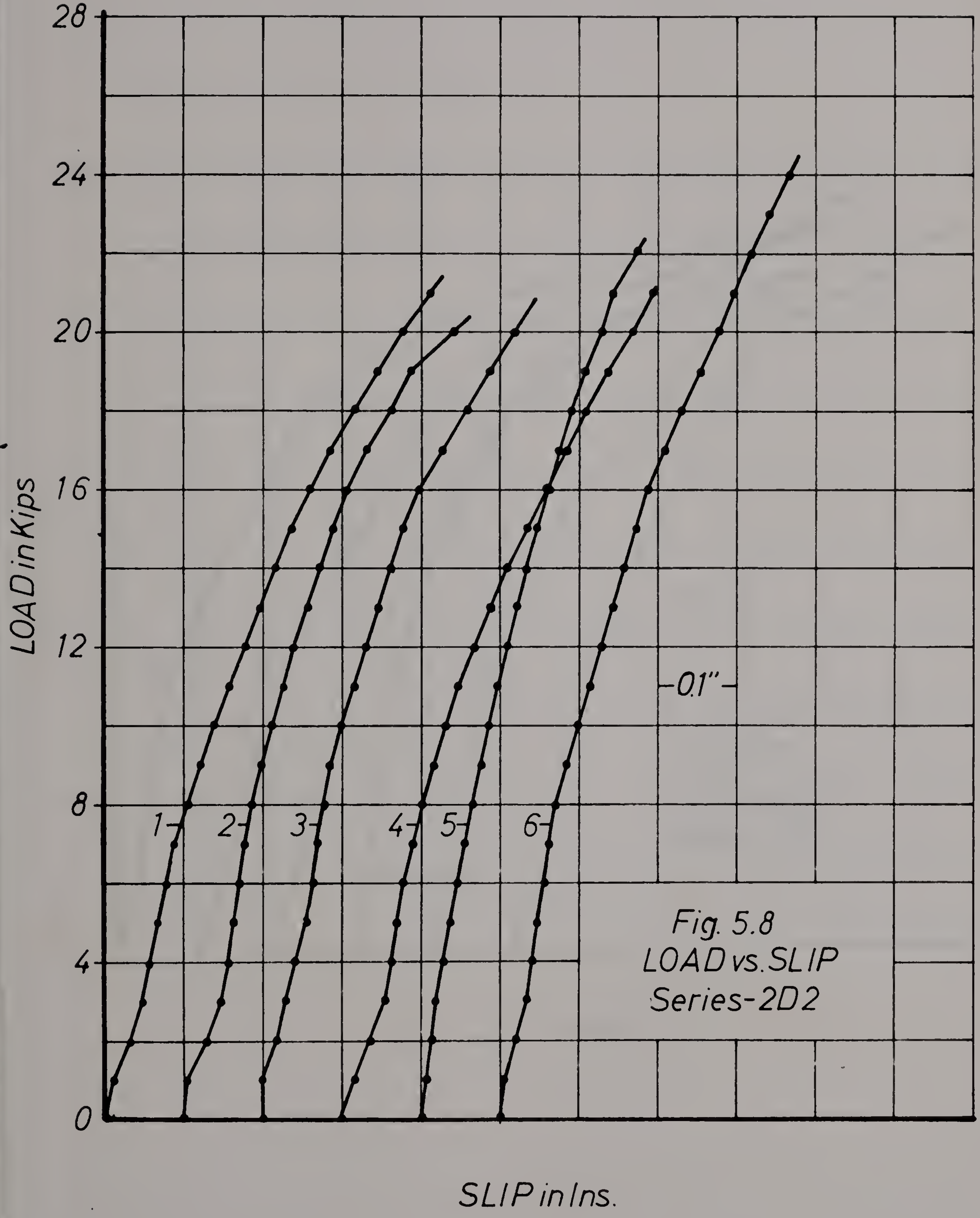
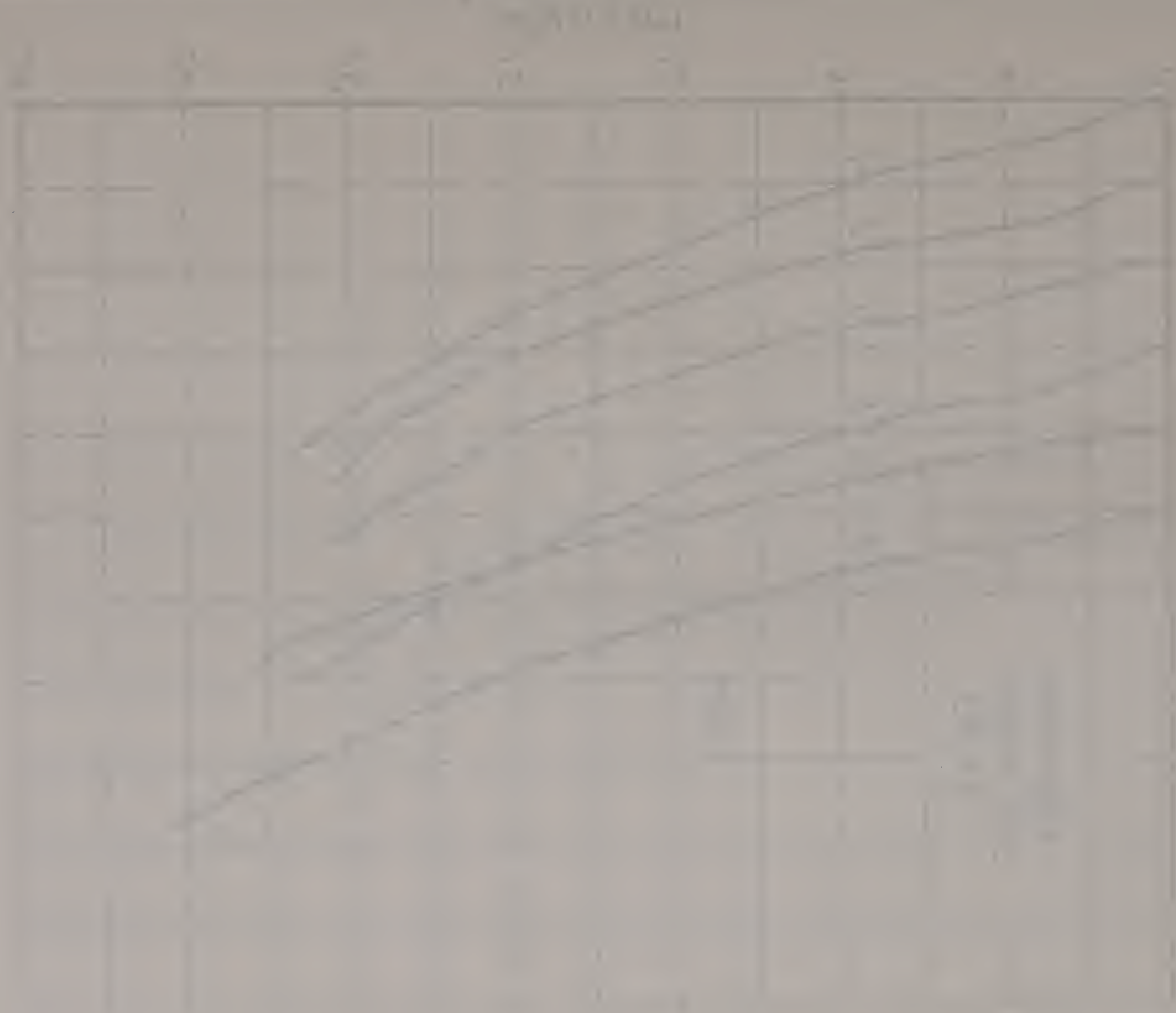


Fig. 5.8
LOAD vs. SLIP
Series-2D2



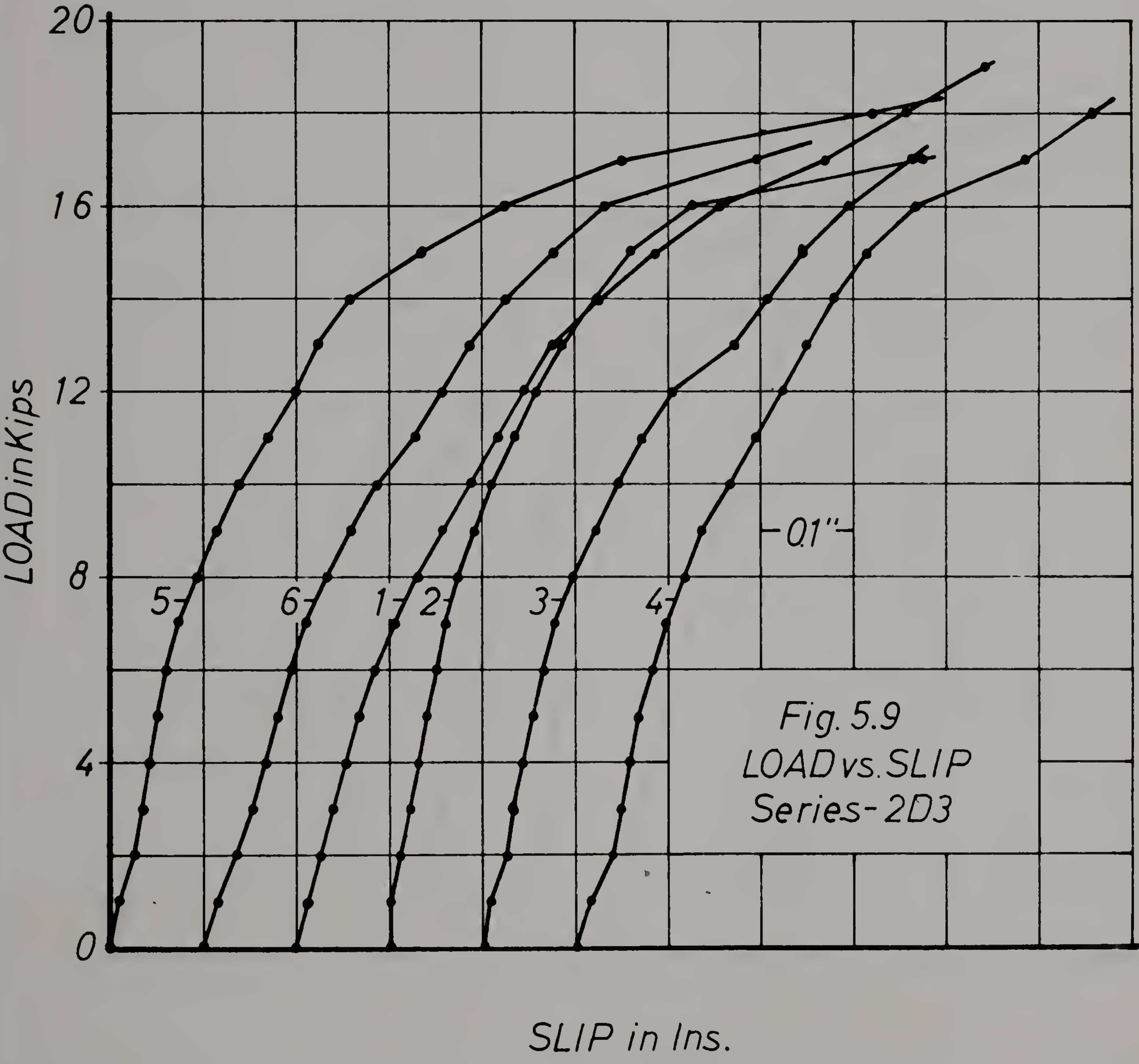


Fig. 5.9
LOAD vs. SLIP
Series-2D3

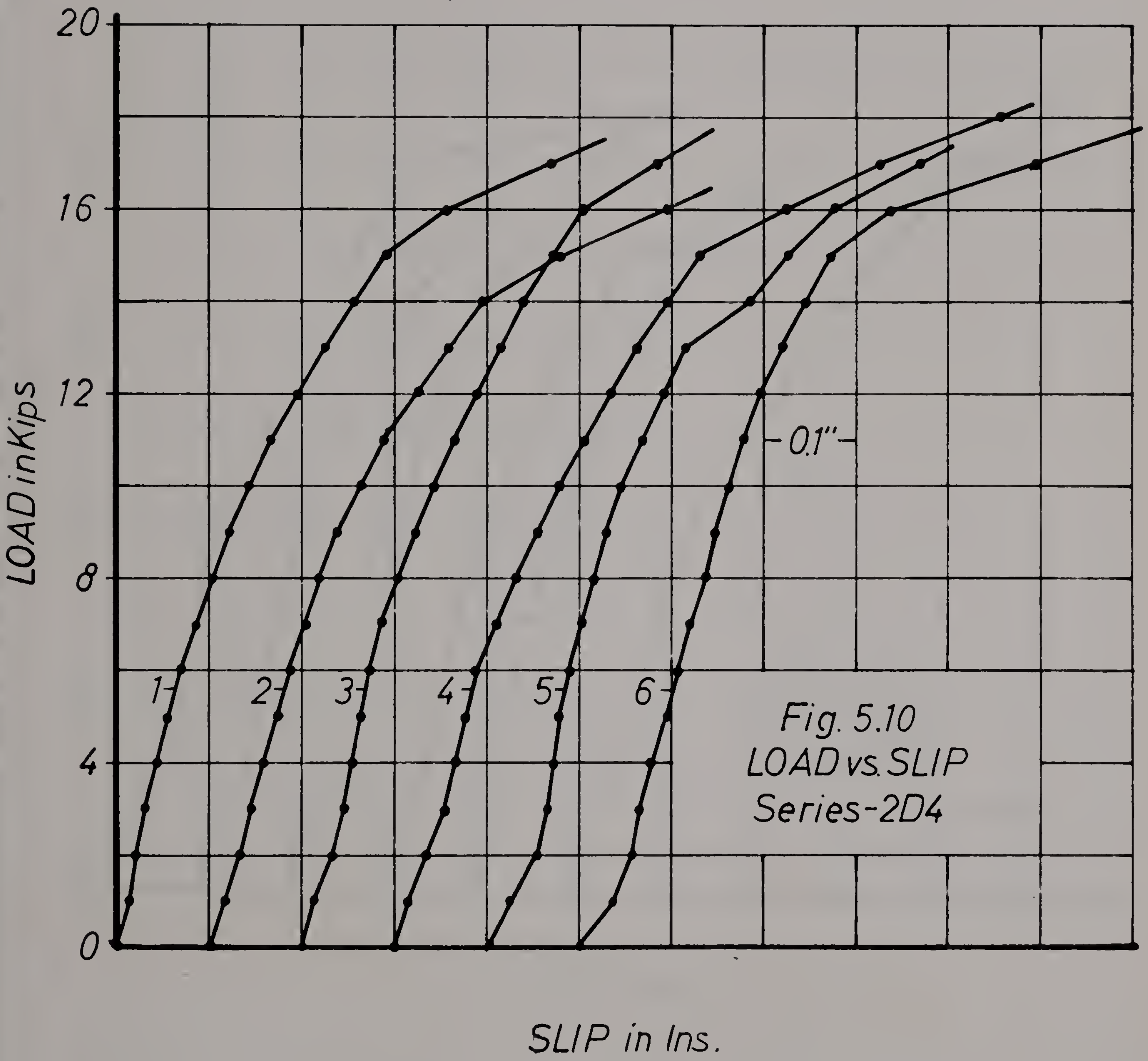
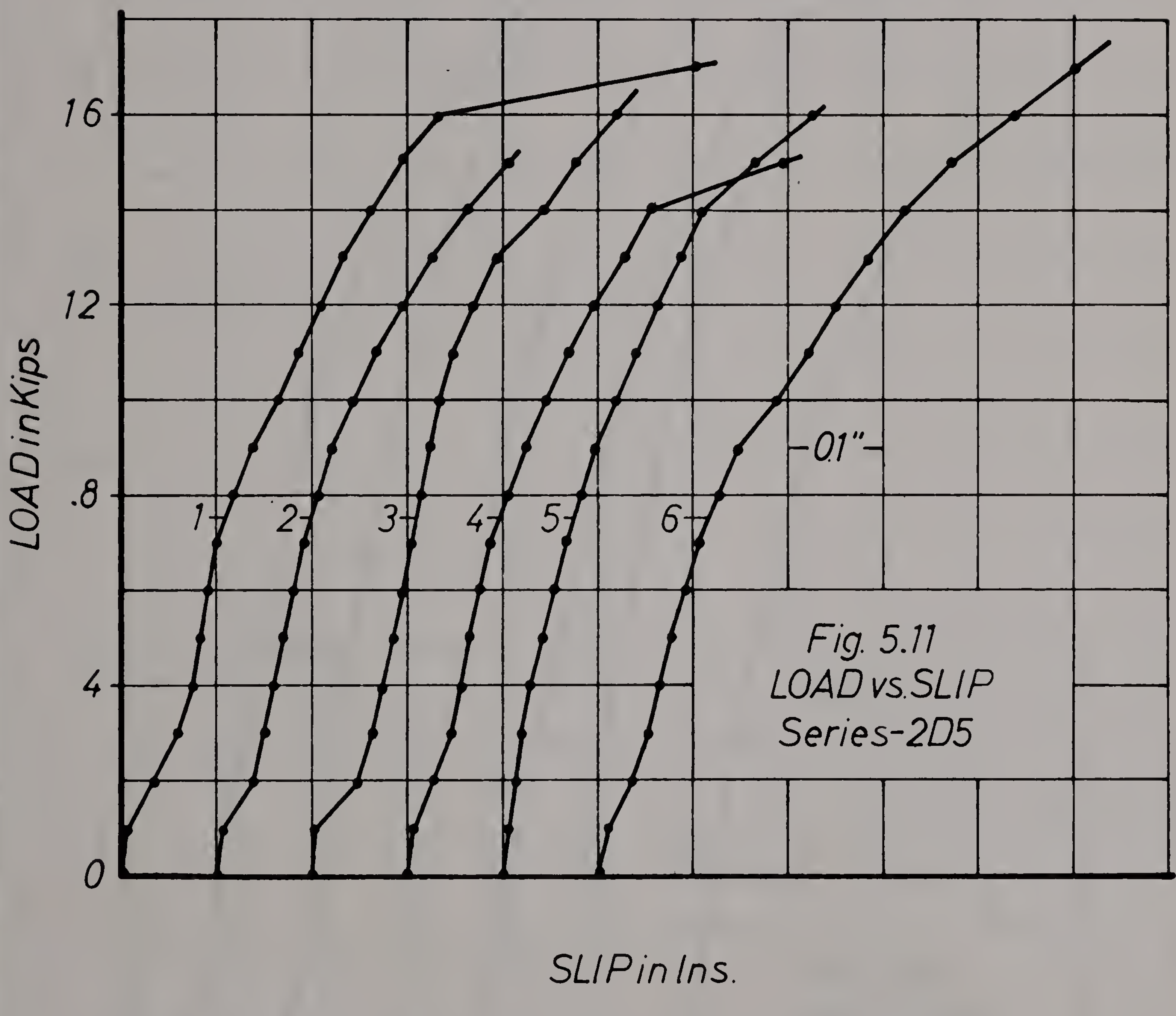


Fig. 5.10
LOAD vs. SLIP
Series-2D4


16
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LOAD in Kips
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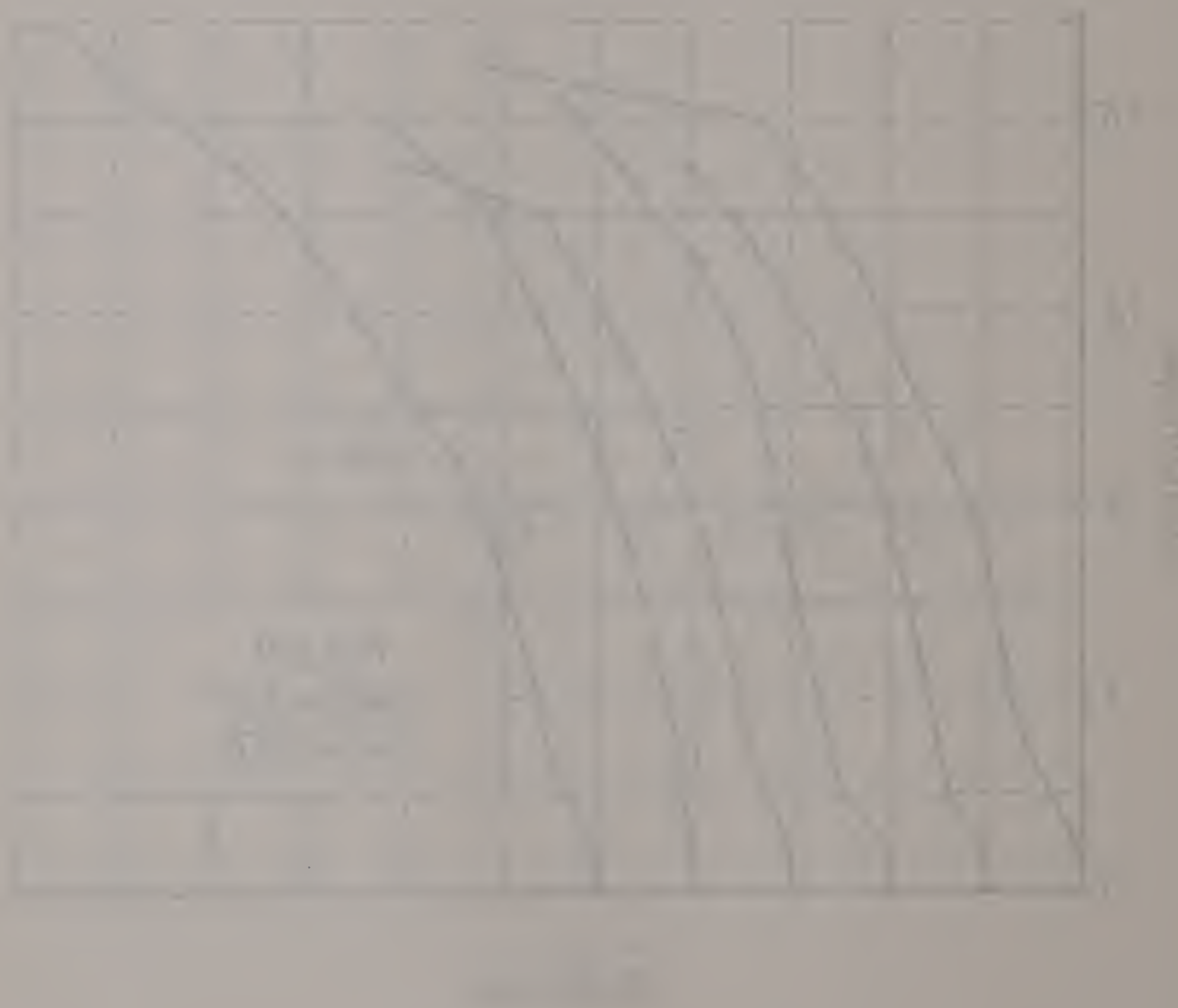
Fig. 5.11
LOAD vs. SLIP
Series-2D5
SLIP in Ins.



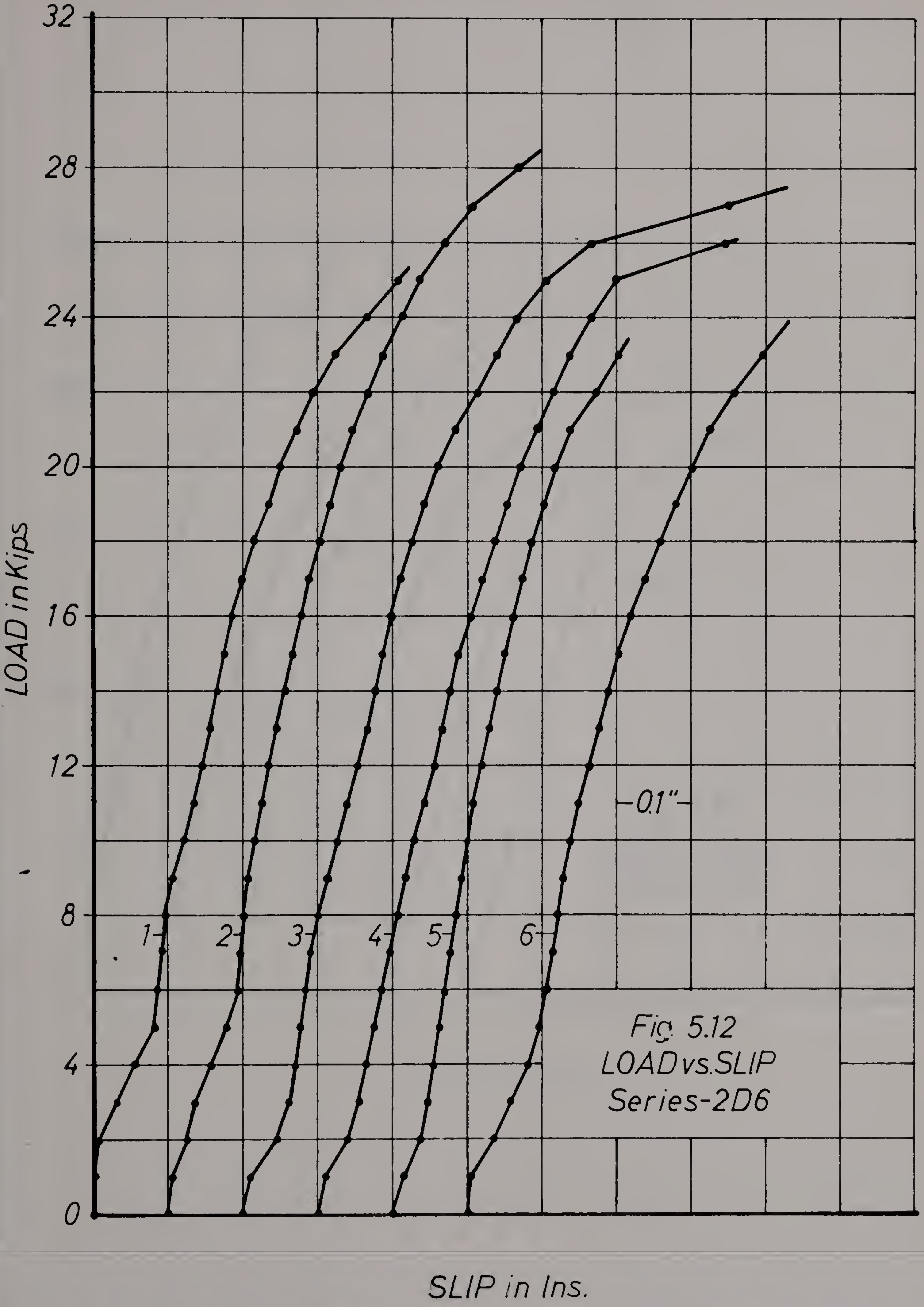


Fig. 5.12
LOAD vs. SLIP
Series-2D6

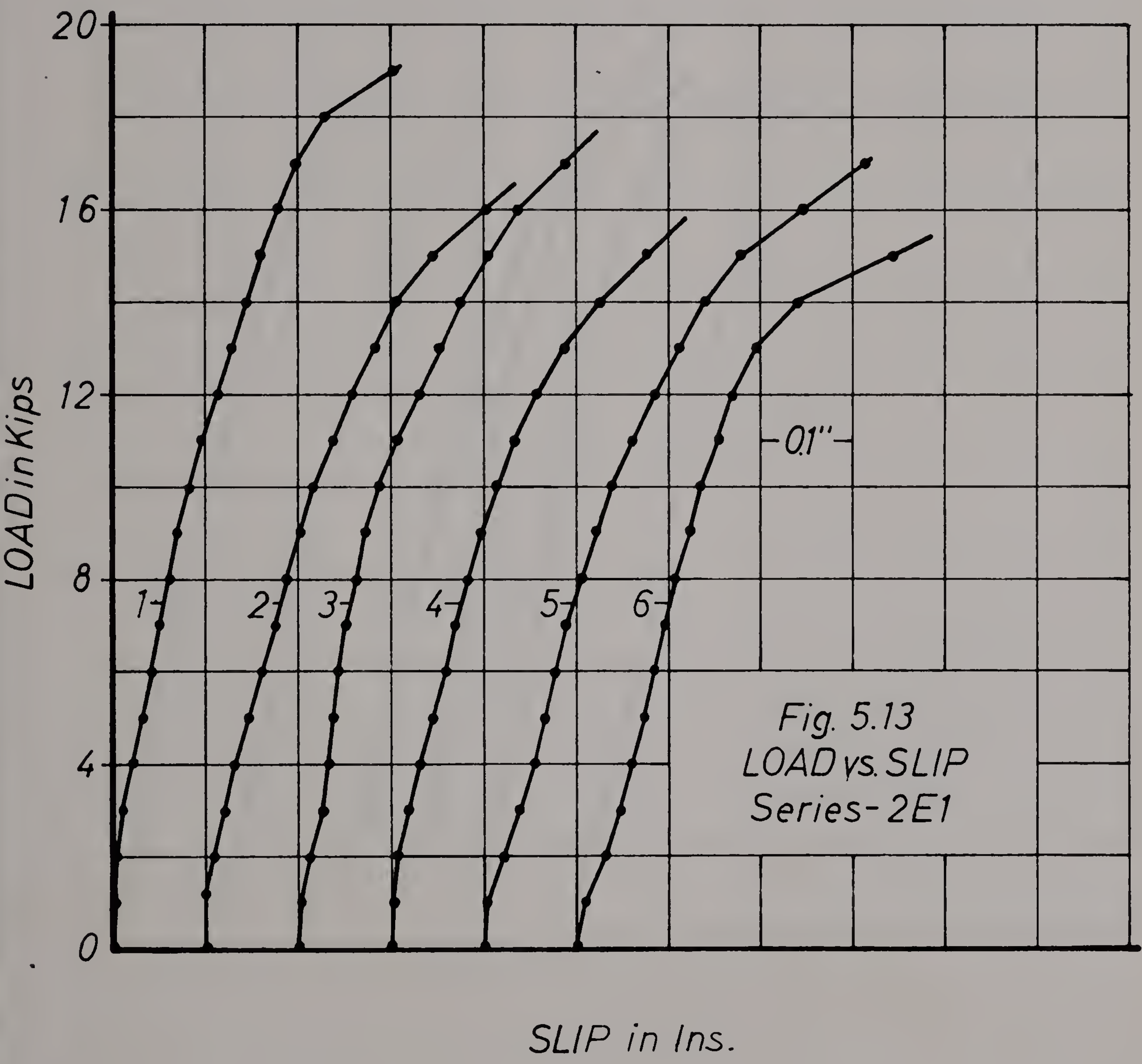


Fig. 5.13
LOAD vs. SLIP
Series-2E1

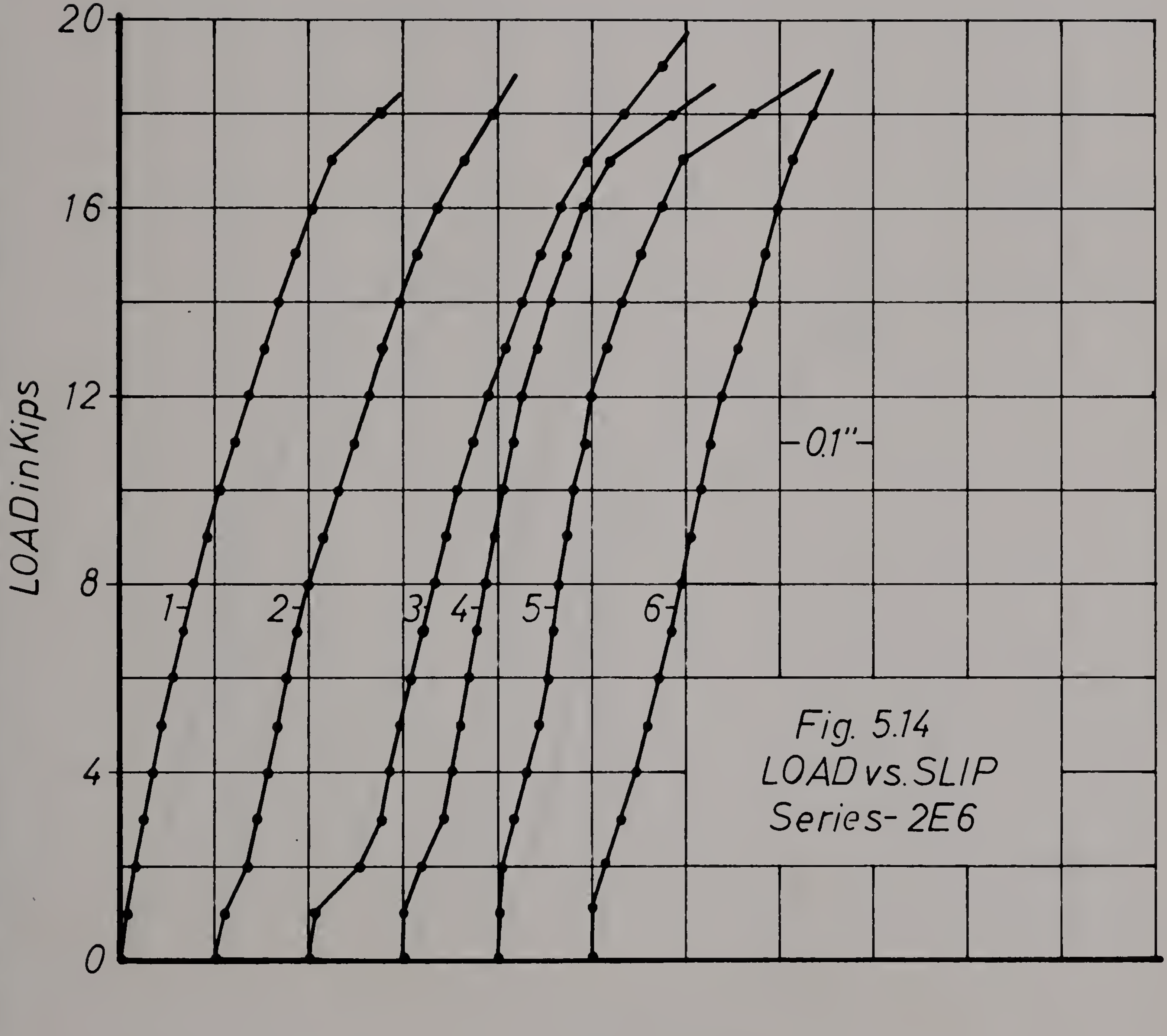
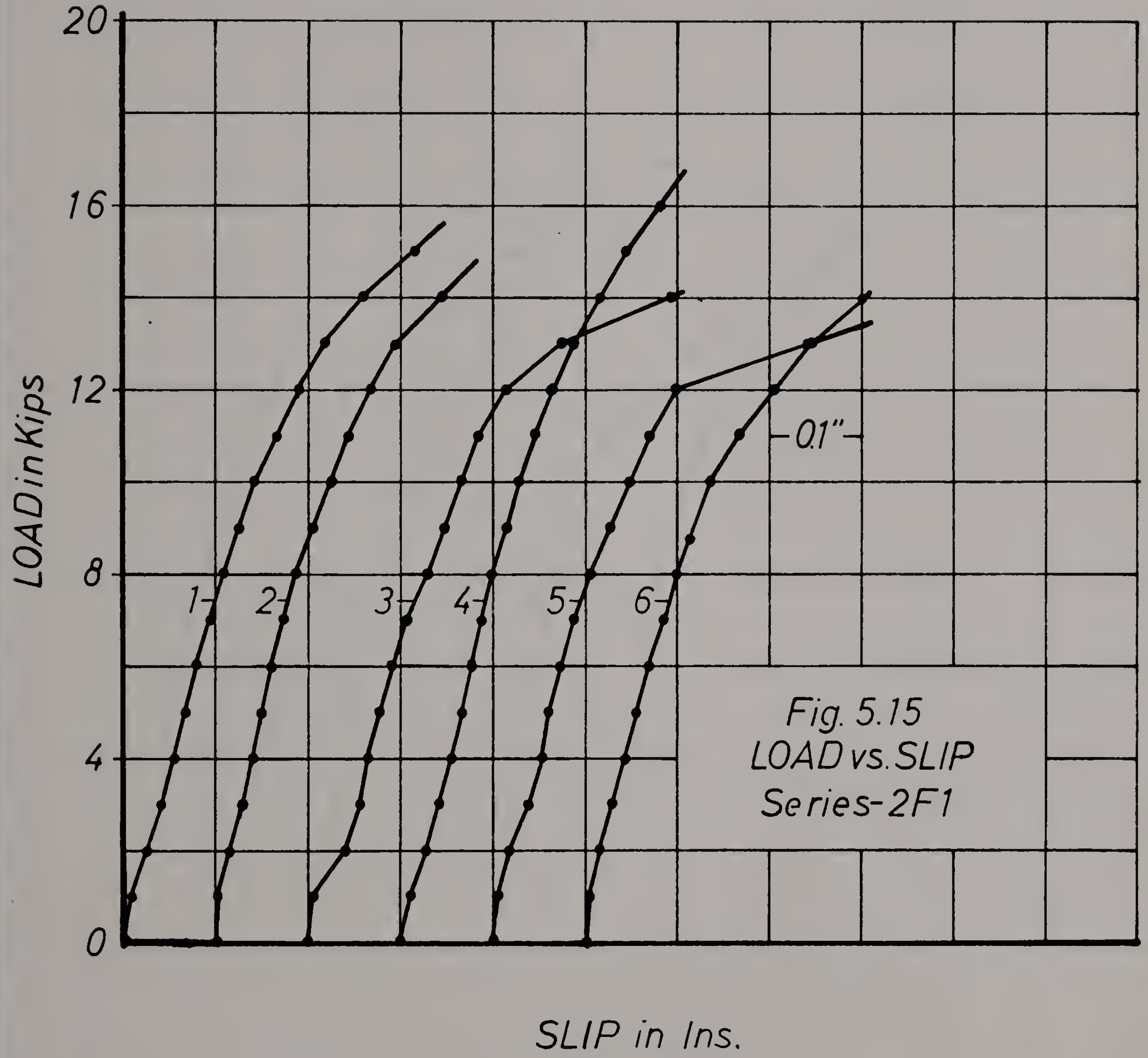


Fig. 5.14
LOAD vs. SLIP
Series- 2E6


20
16
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0
LOAD in Kips
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0.1"
Fig. 5.15
LOAD vs. SLIP
Series-2F1
SLIP in Ins.

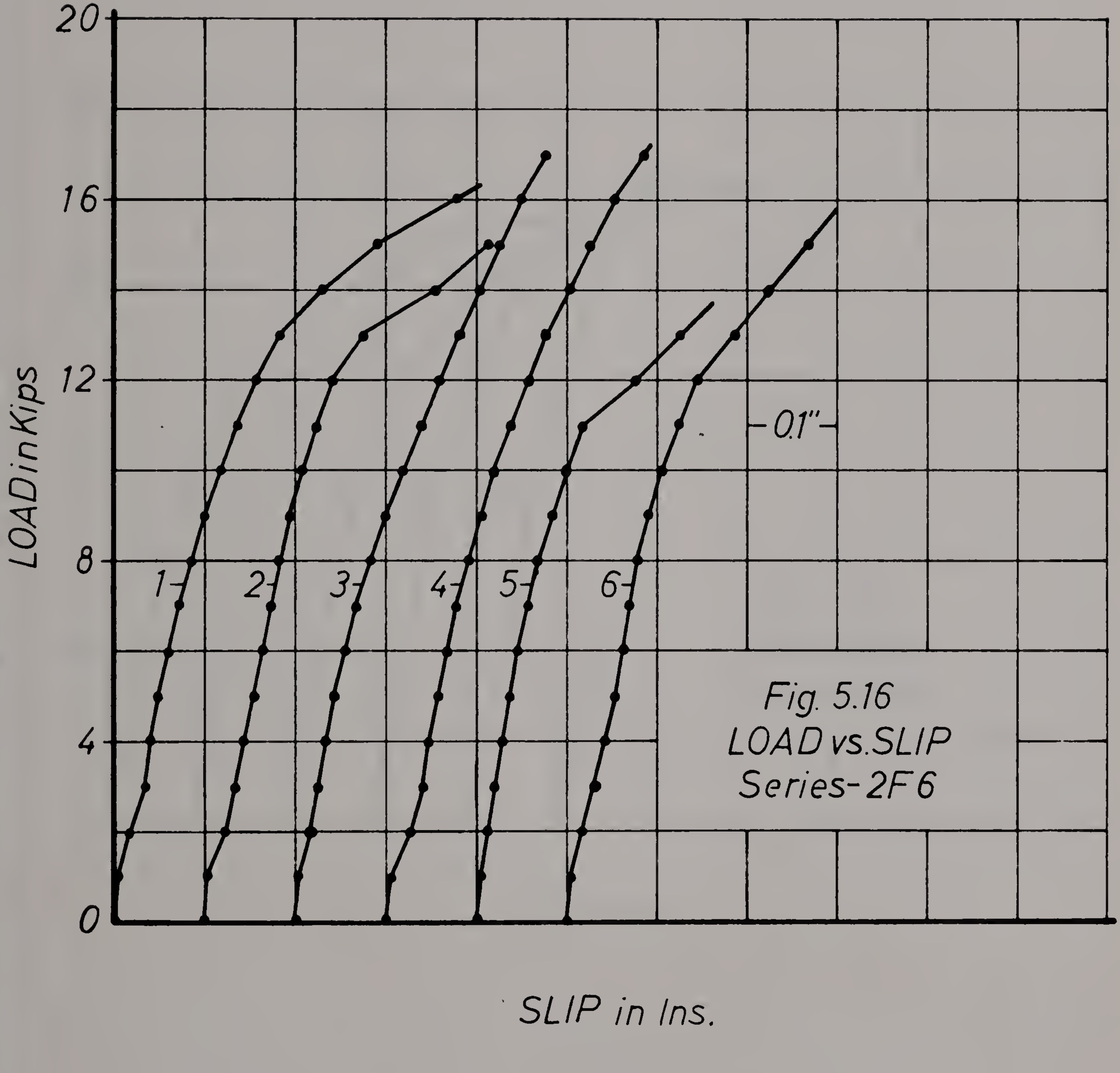


Fig. 5.16
LOAD vs. SLIP
Series-2F6

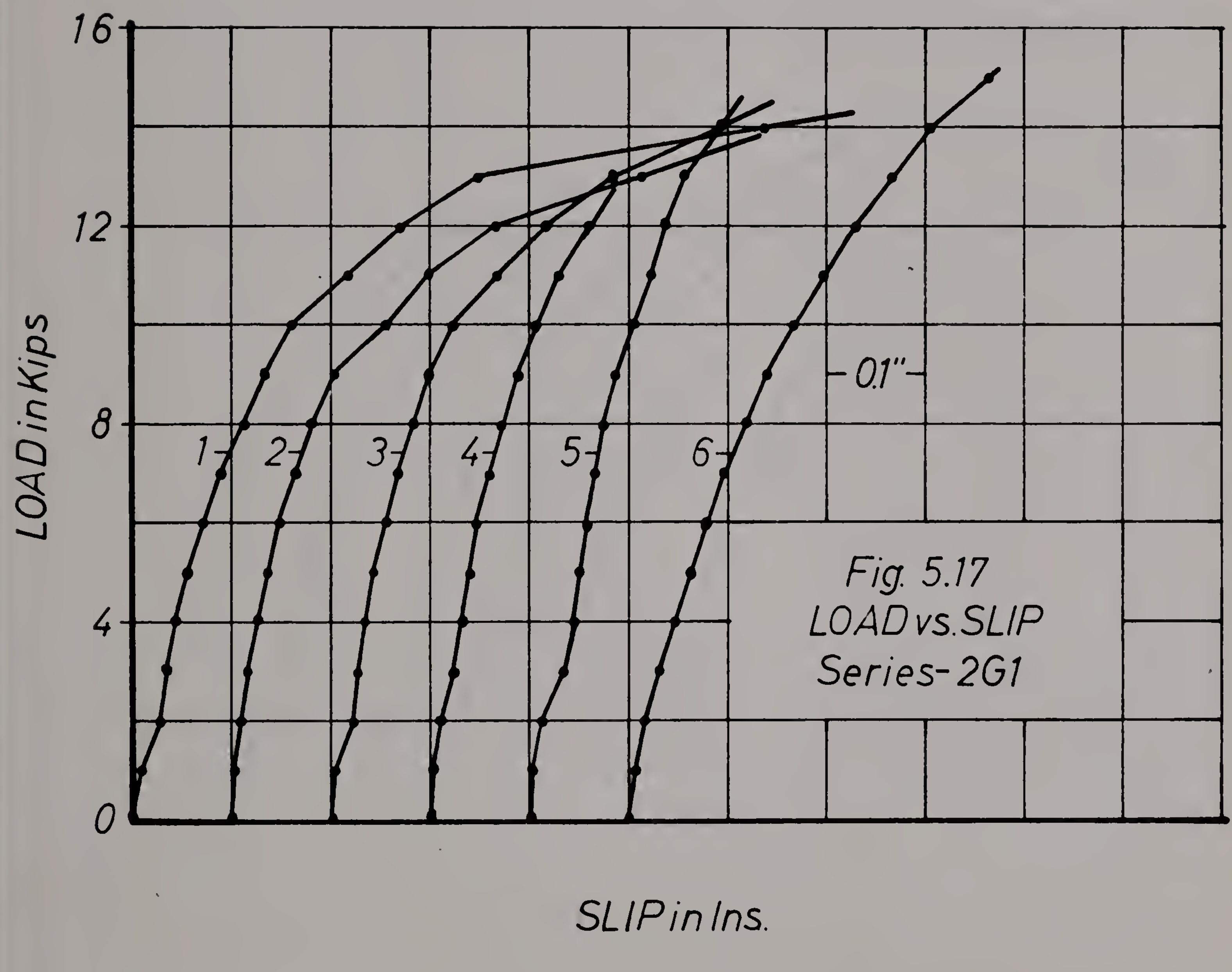


Fig. 5.17
LOAD vs. SLIP
Series-2G1

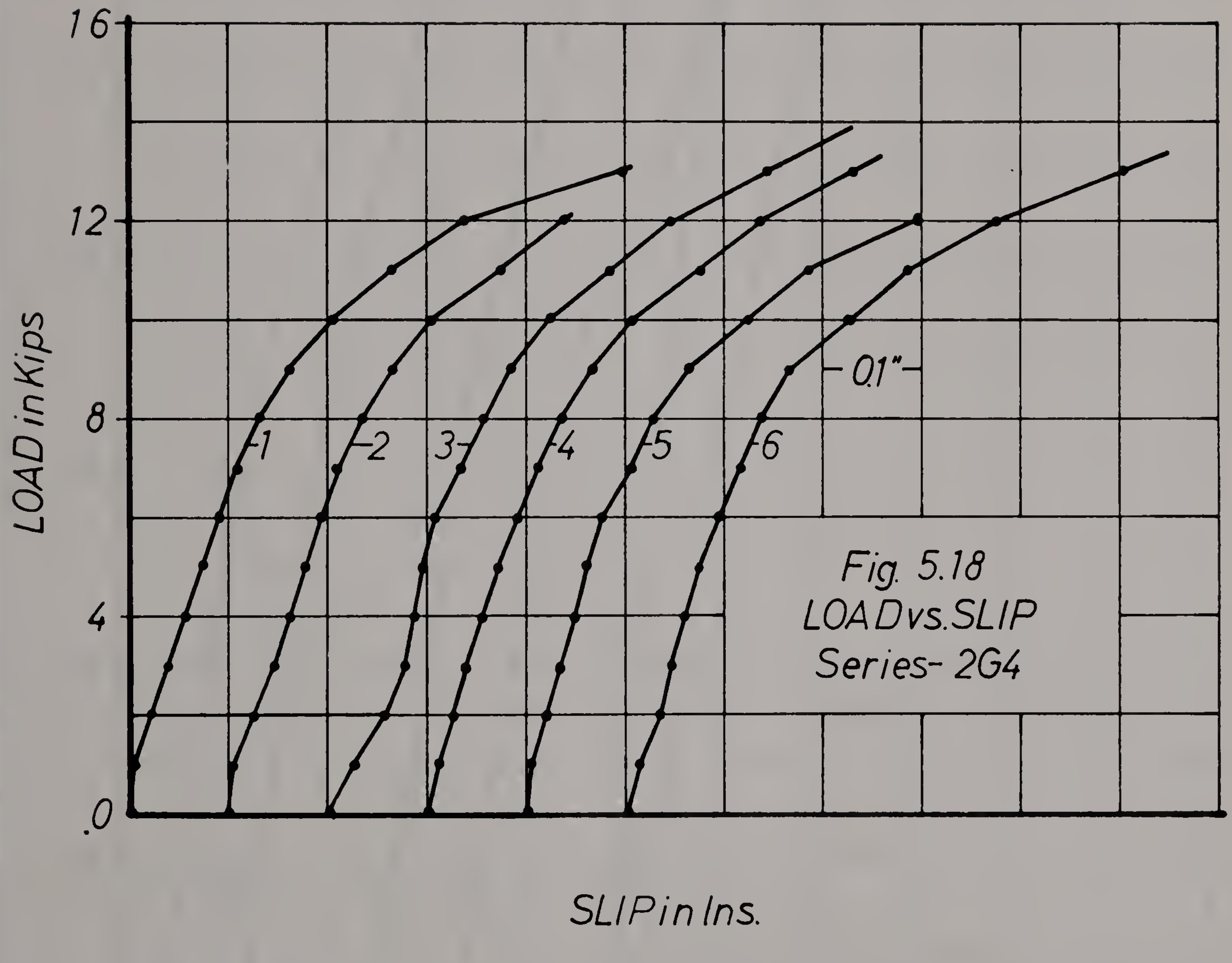


Fig. 5.18
LOAD vs. SLIP
Series- 2G4

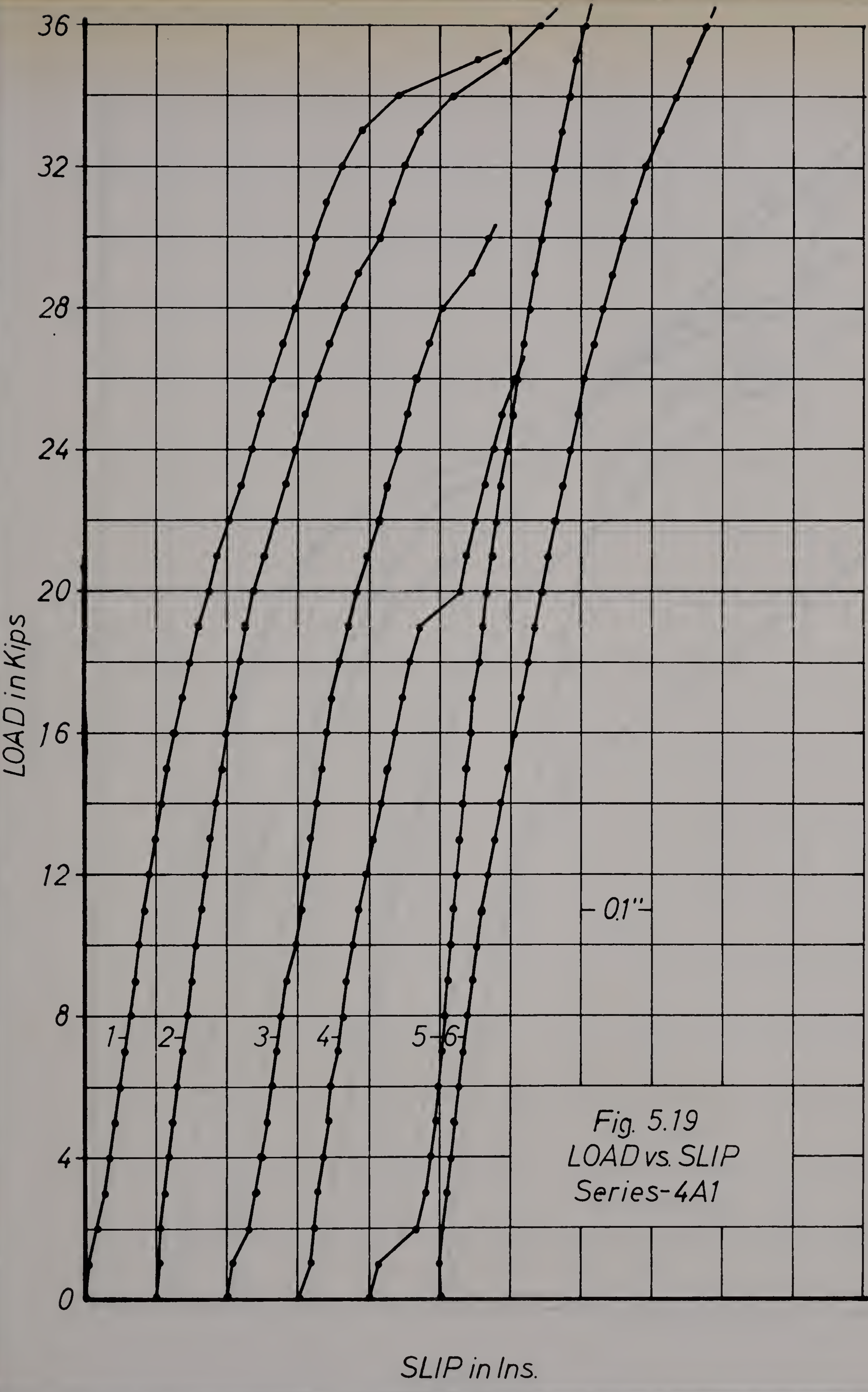
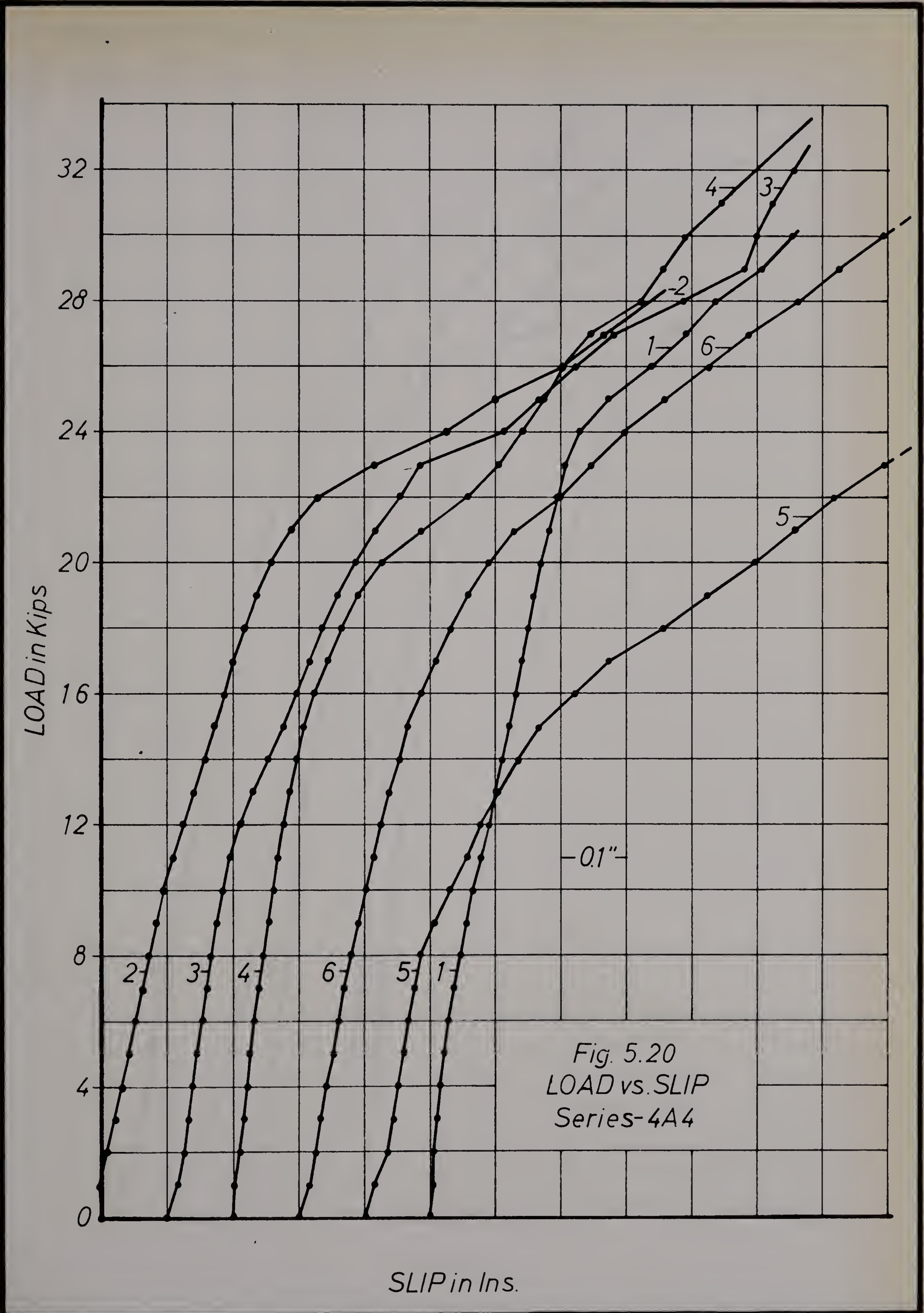


Fig. 5.19
LOAD vs. SLIP
Series-4A1



LOAD in Kips
SLIP in Ins.
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28
32
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-0.1"-
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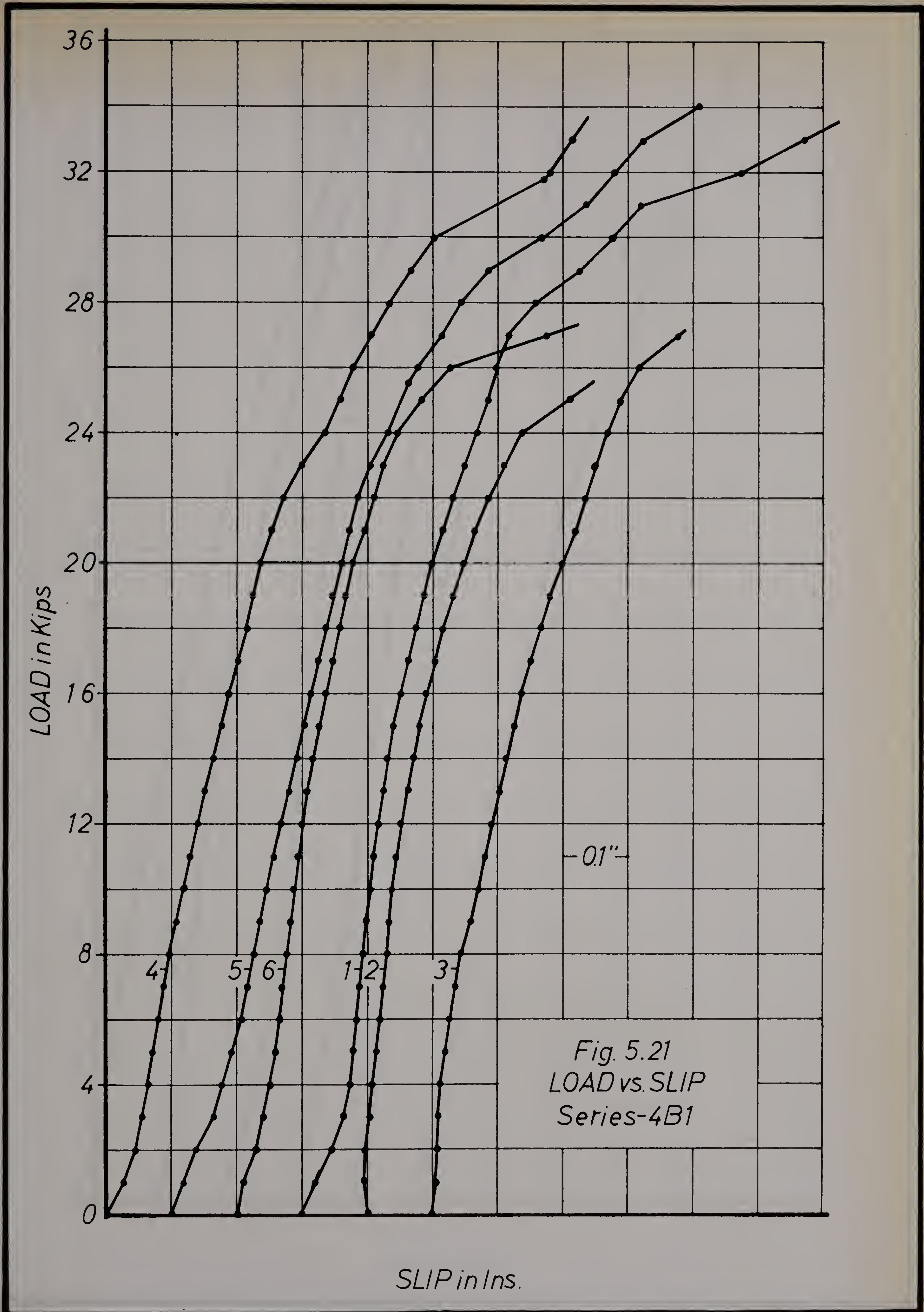
6
Fig. 5.20
LOAD vs. SLIP
Series-4A4


36
32
28
24
20
16
12
8
4
0
LOAD in Kips
SLIP in Ins.
0.1"
4
5
6
1
2
3
Fig. 5.21
LOAD vs. SLIP
Series-4B1

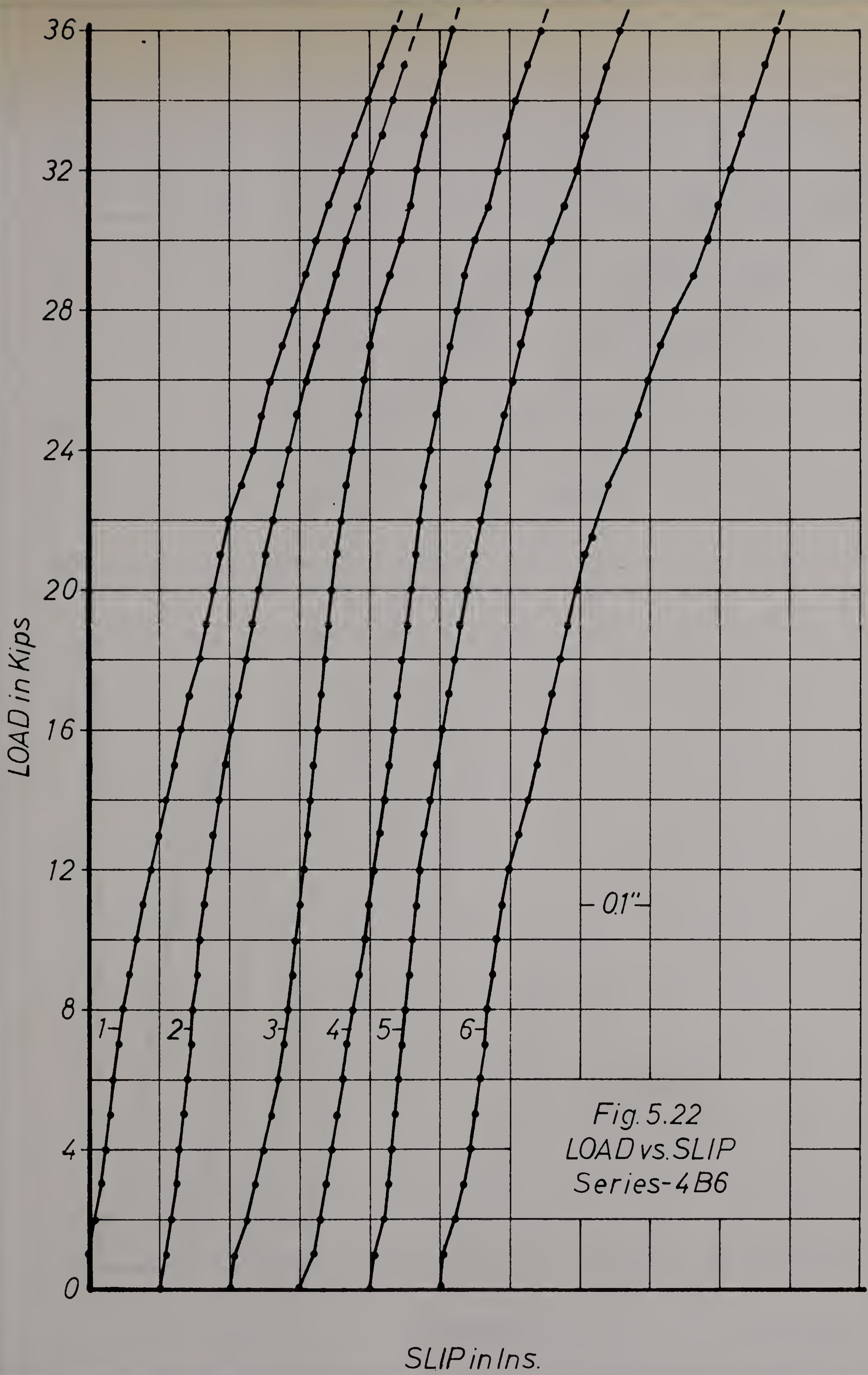


Fig. 5.22
LOAD vs. SLIP
Series-4B6

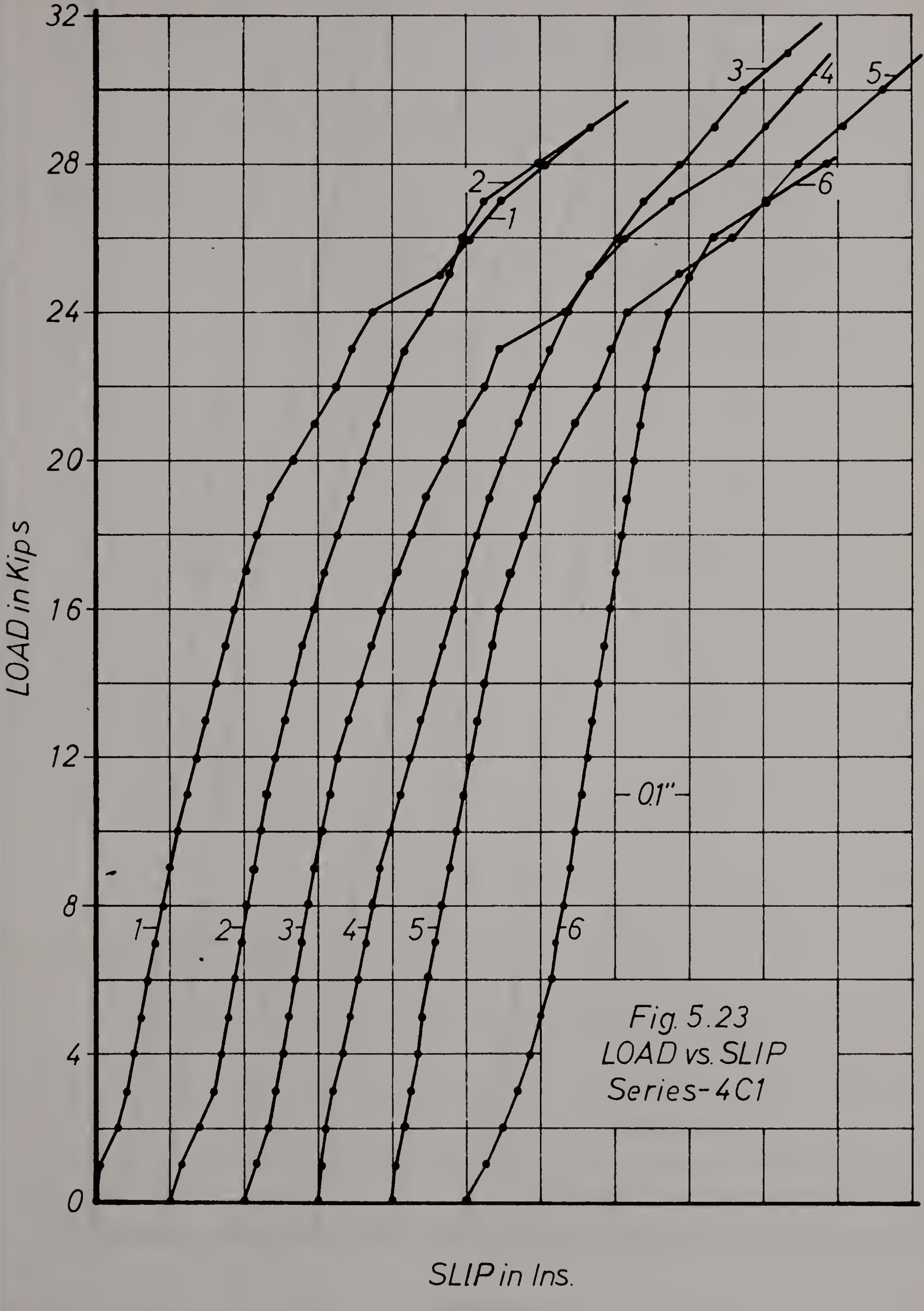


Fig. 5.23
LOAD vs. SLIP
Series-4C1

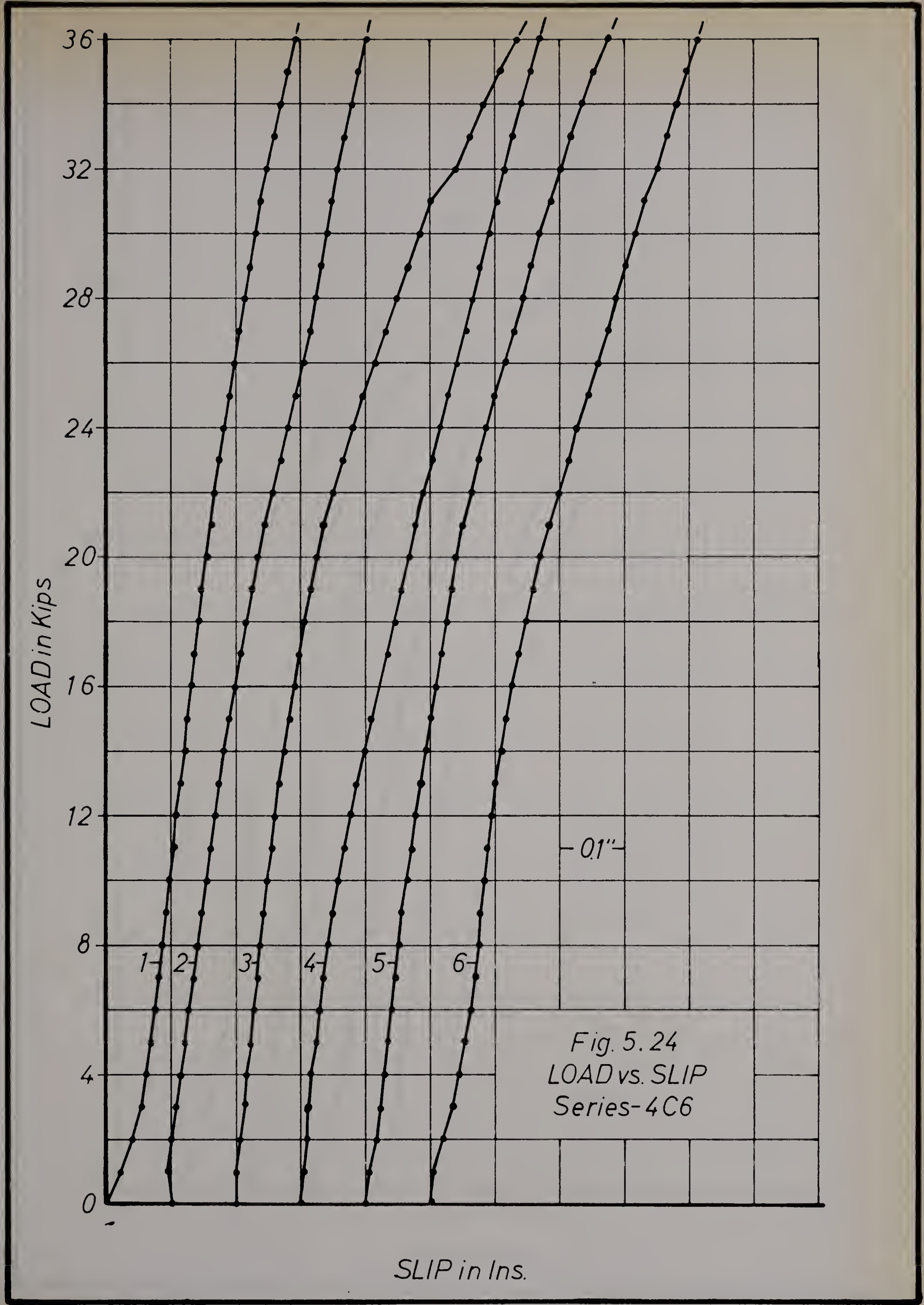


Fig. 5.24
LOAD vs. SLIP
Series-4C6

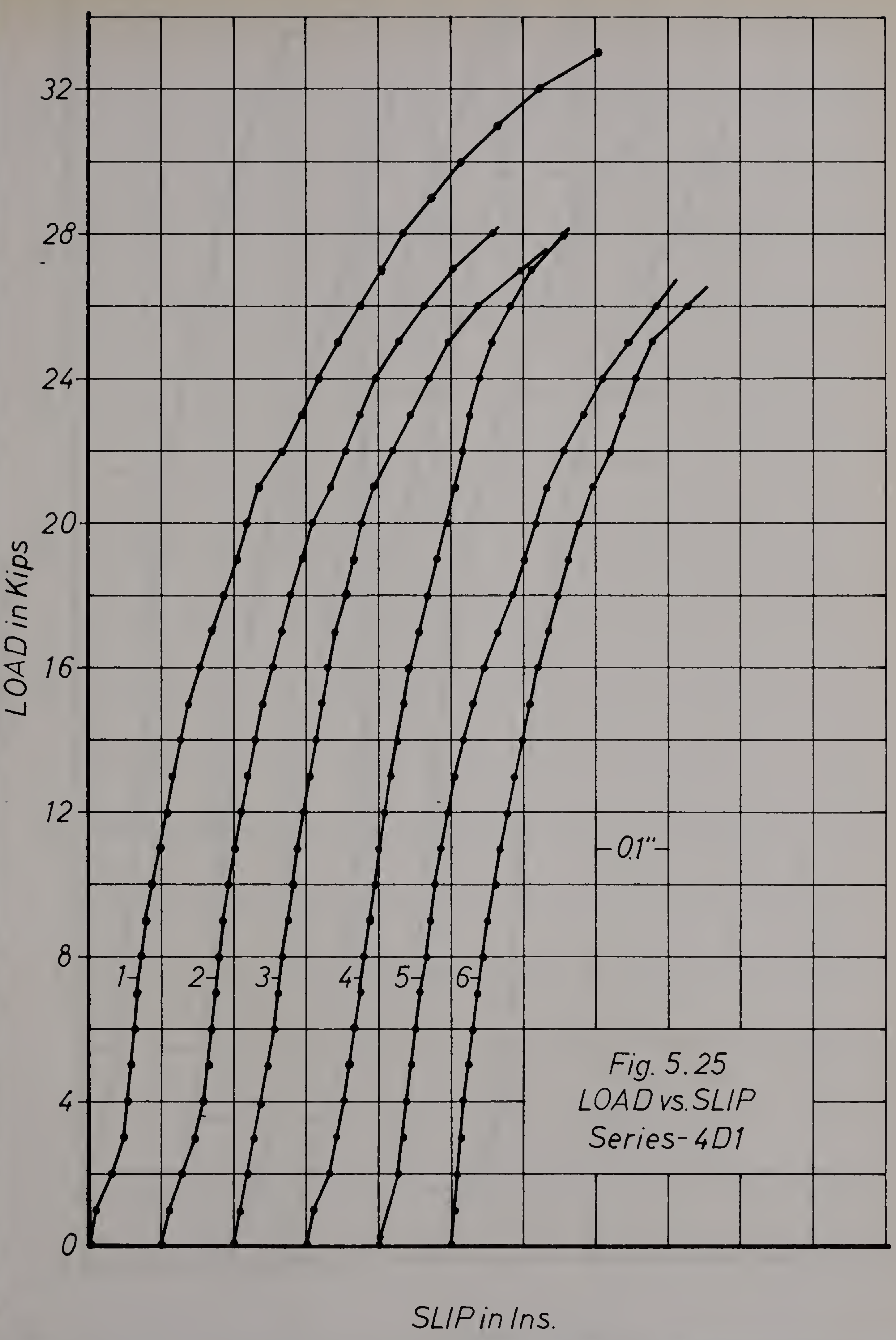


Fig. 5.25
LOAD vs. SLIP
Series-4D1

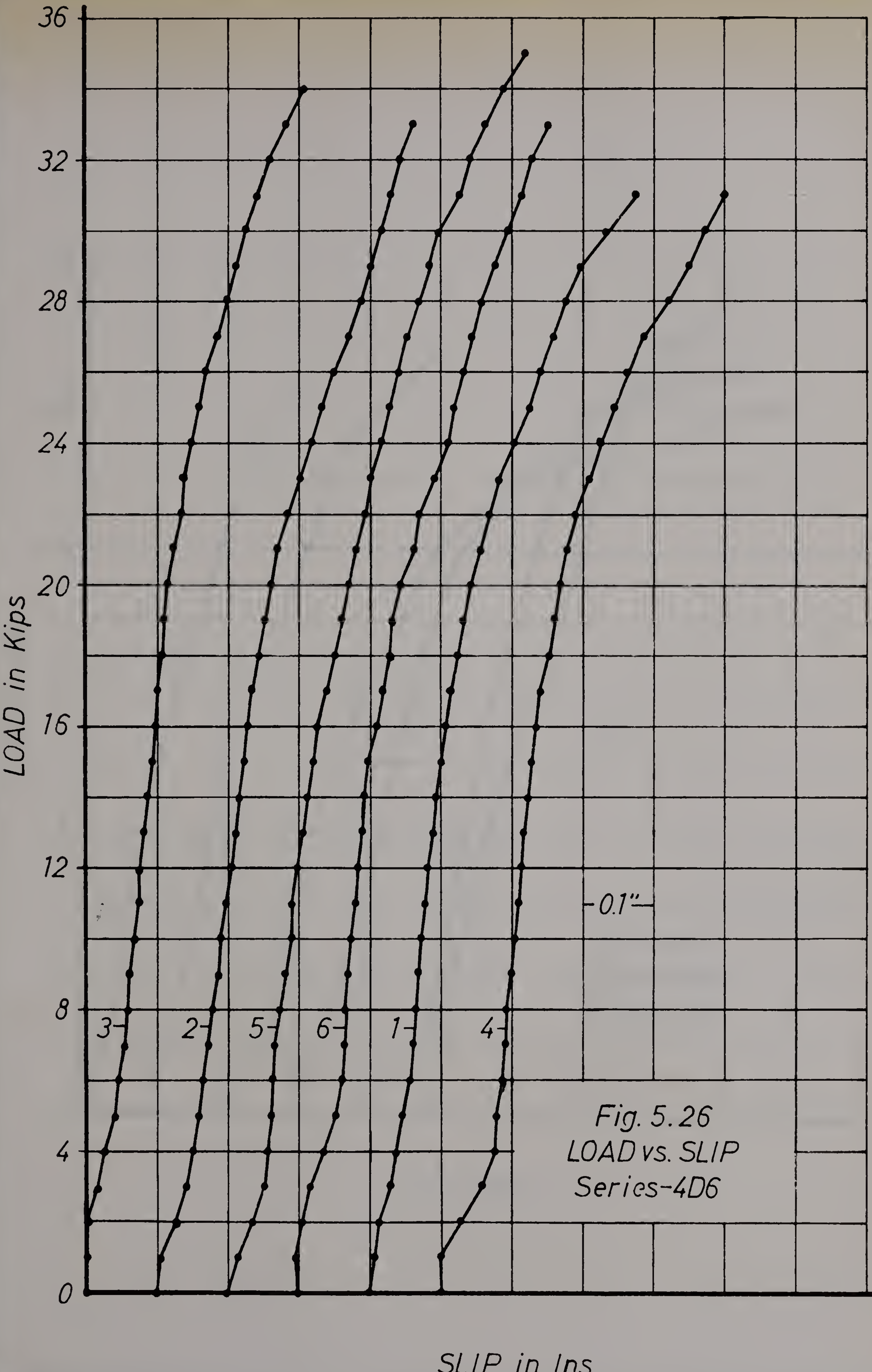


Fig. 5.26
LOAD vs. SLIP
Series-4D6

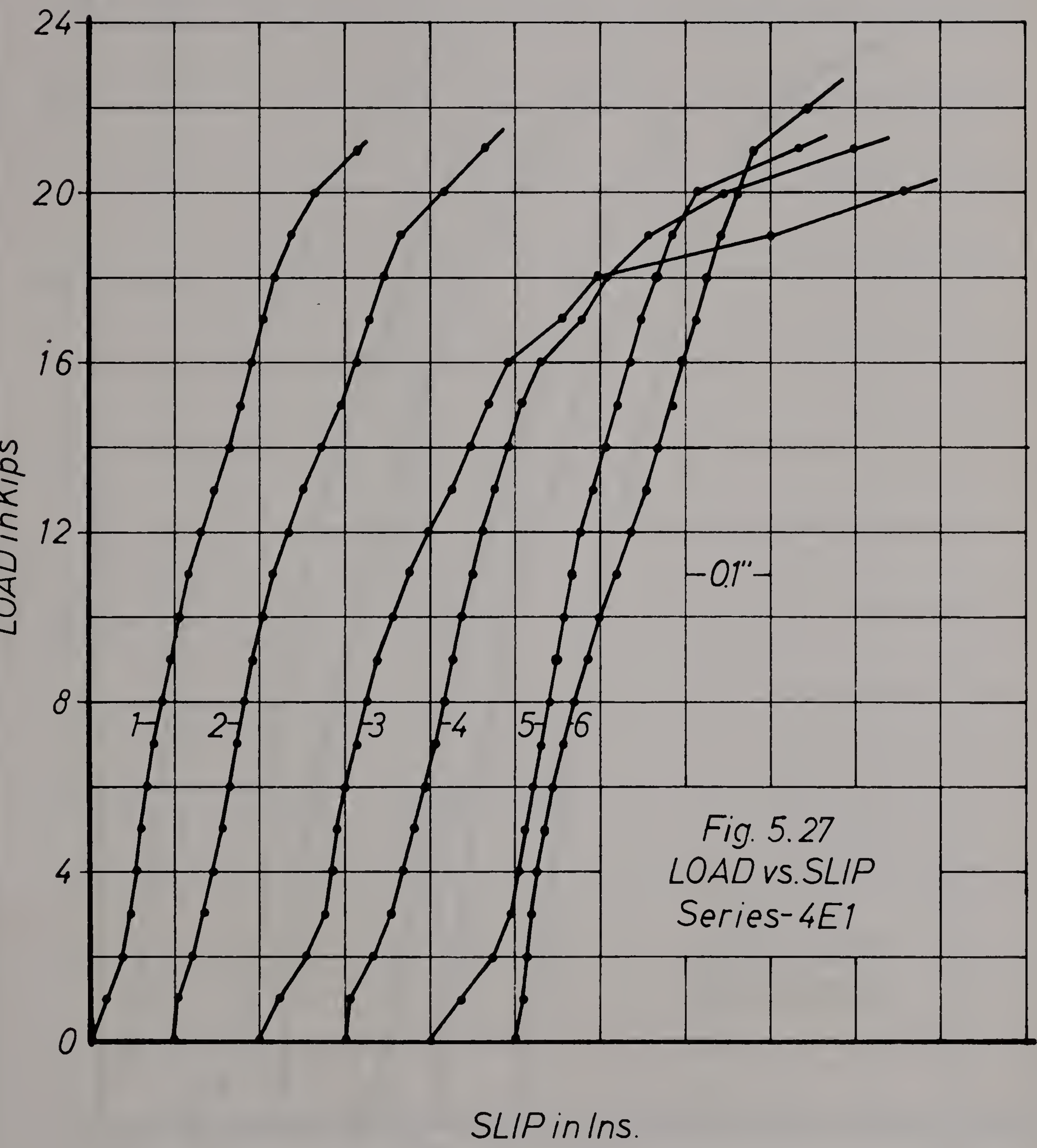


Fig. 5.27
LOAD vs. SLIP
Series-4E1

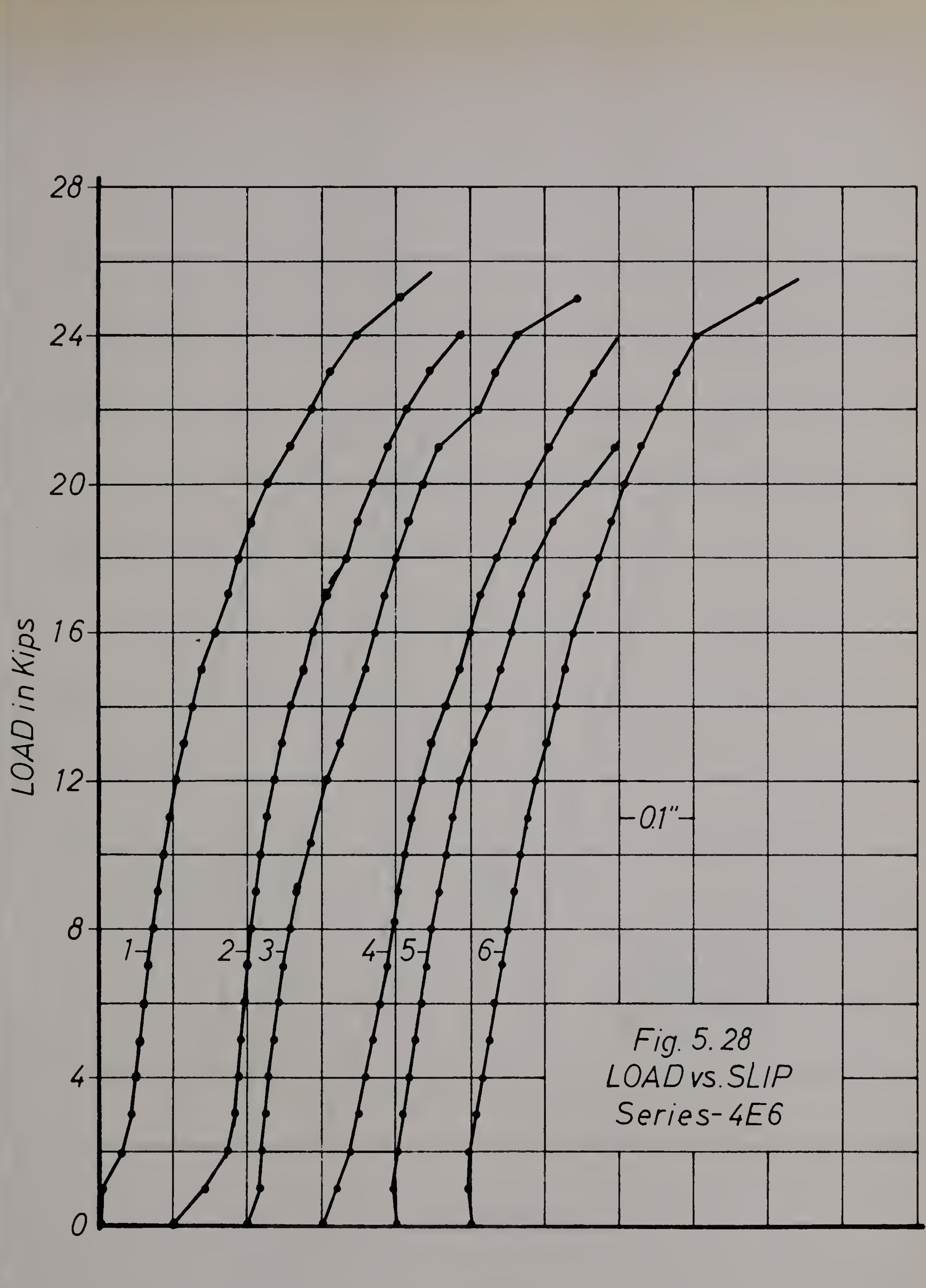
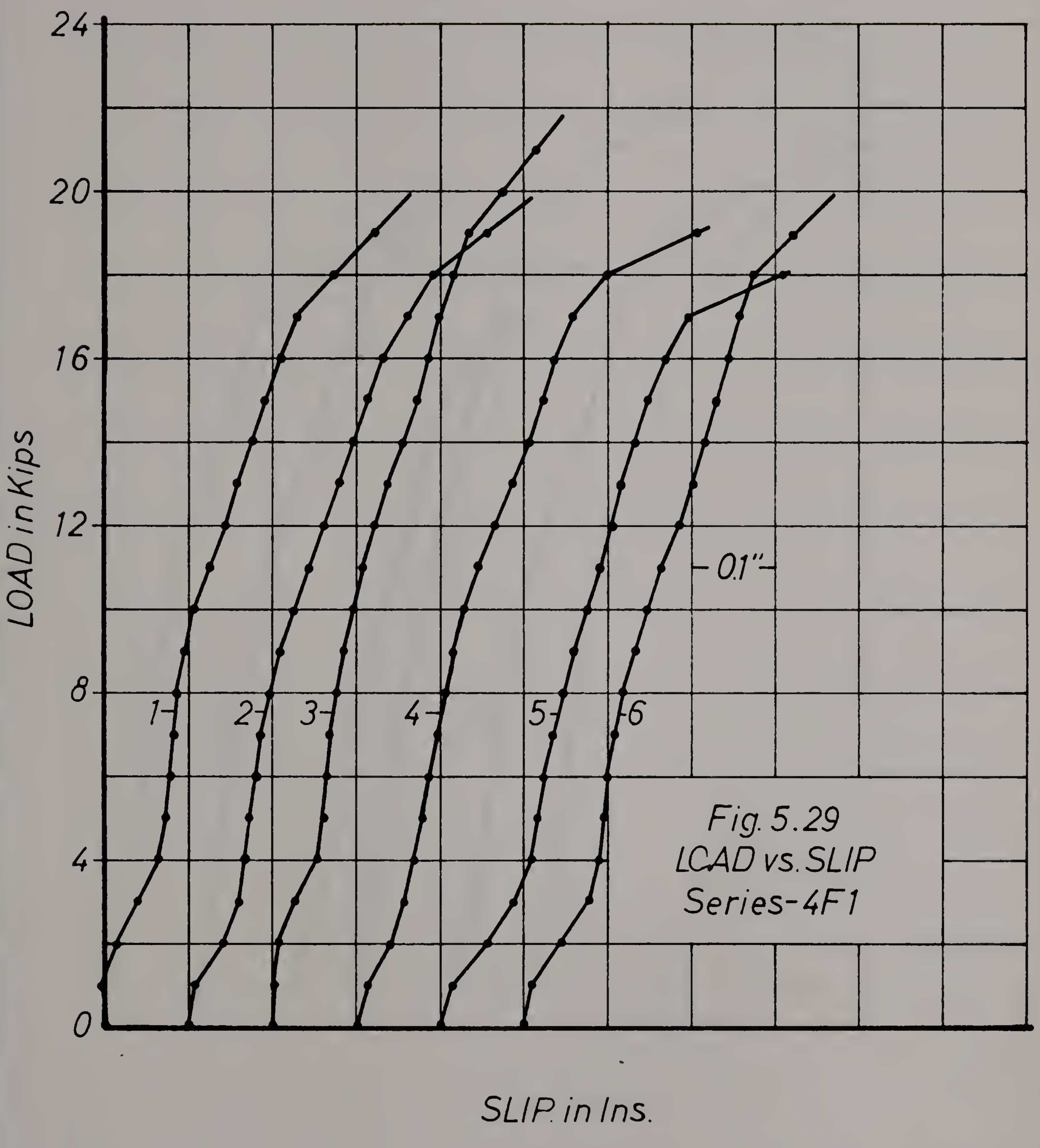


Fig. 5.28
LOAD vs. SLIP
Series-4E6


24
20
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LOAD in Kips
SLIP in Ins.
0.1"
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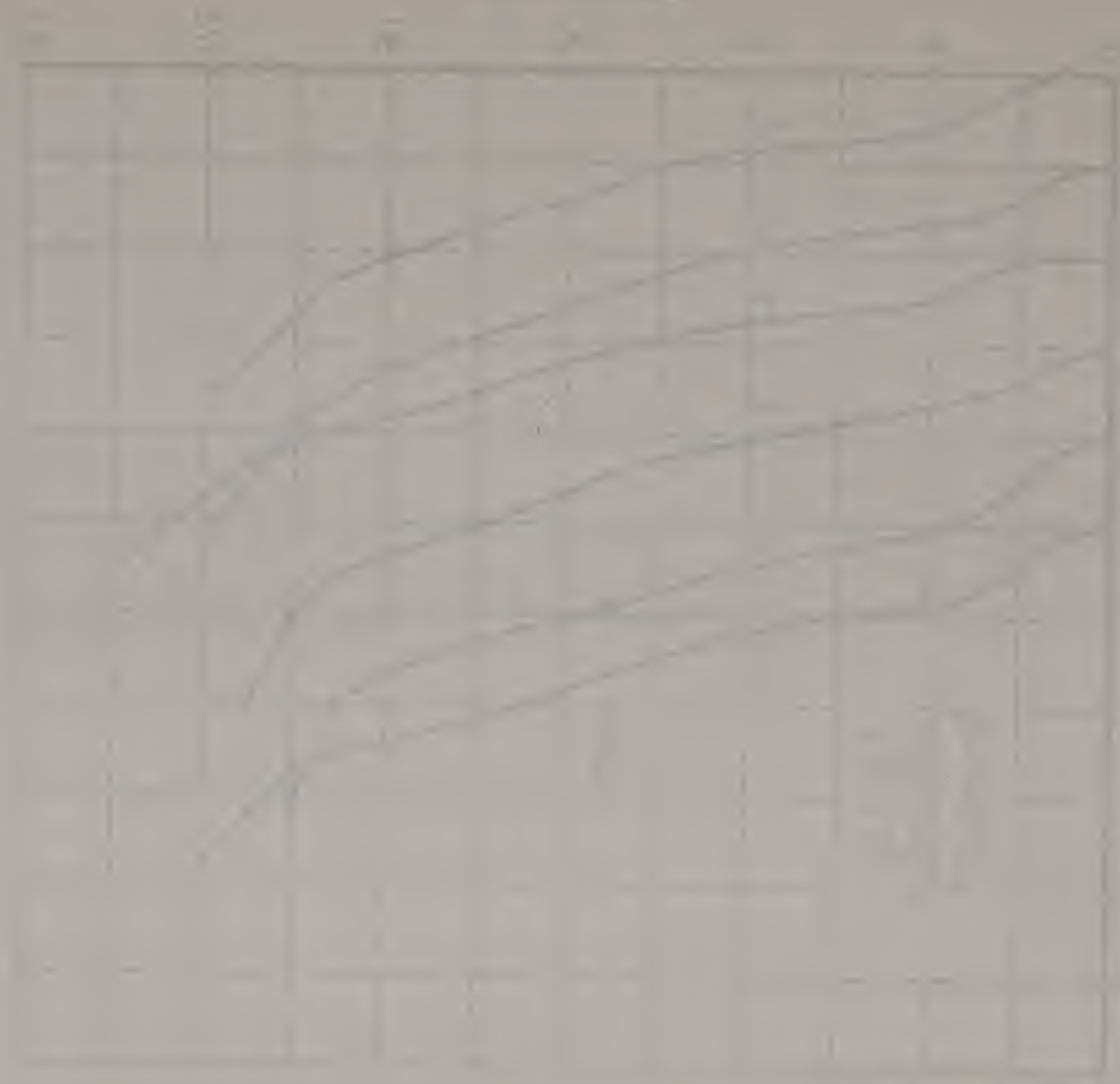
3
4
5
6
Fig. 5.29
LOAD vs. SLIP
Series-4F1



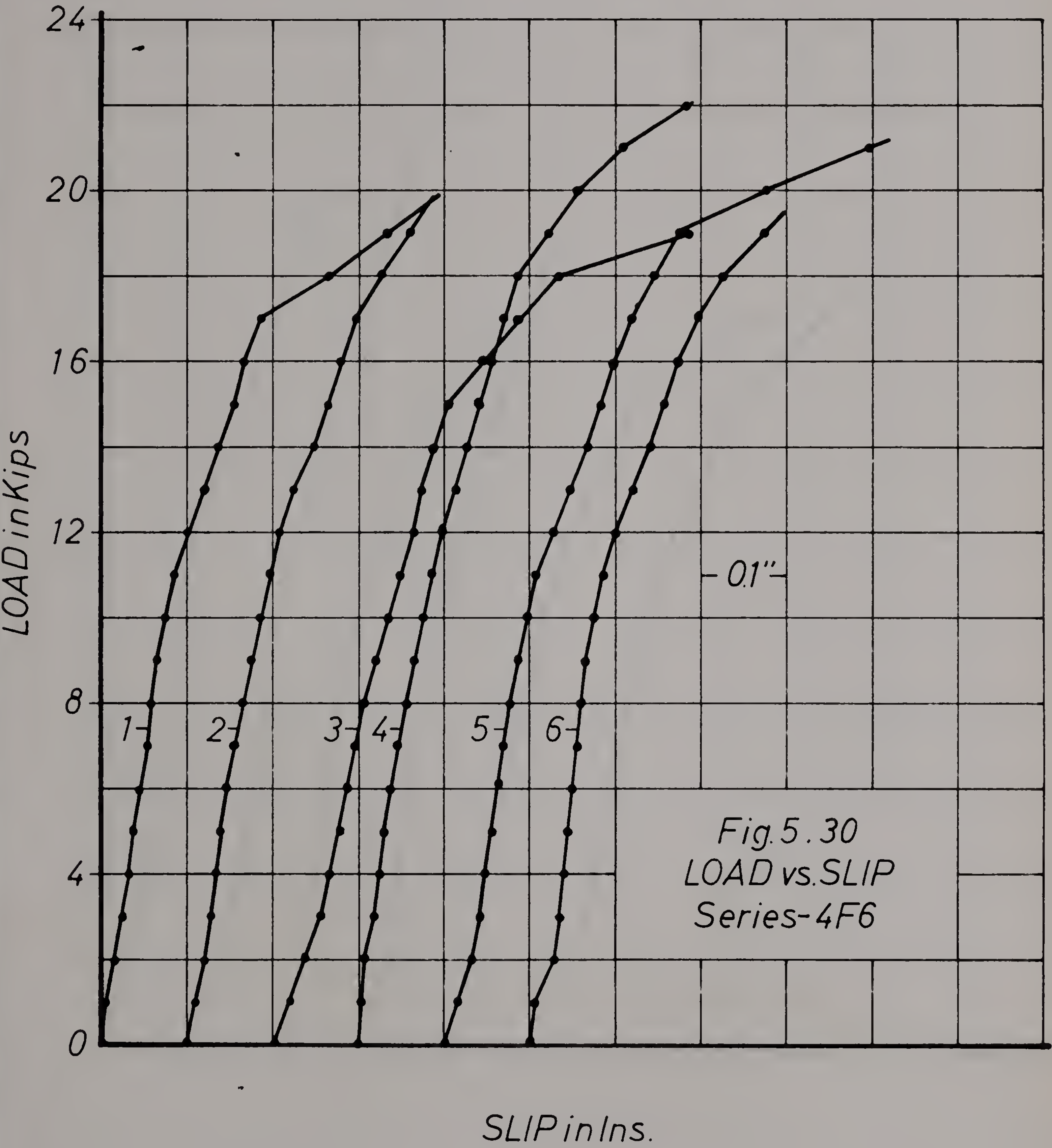
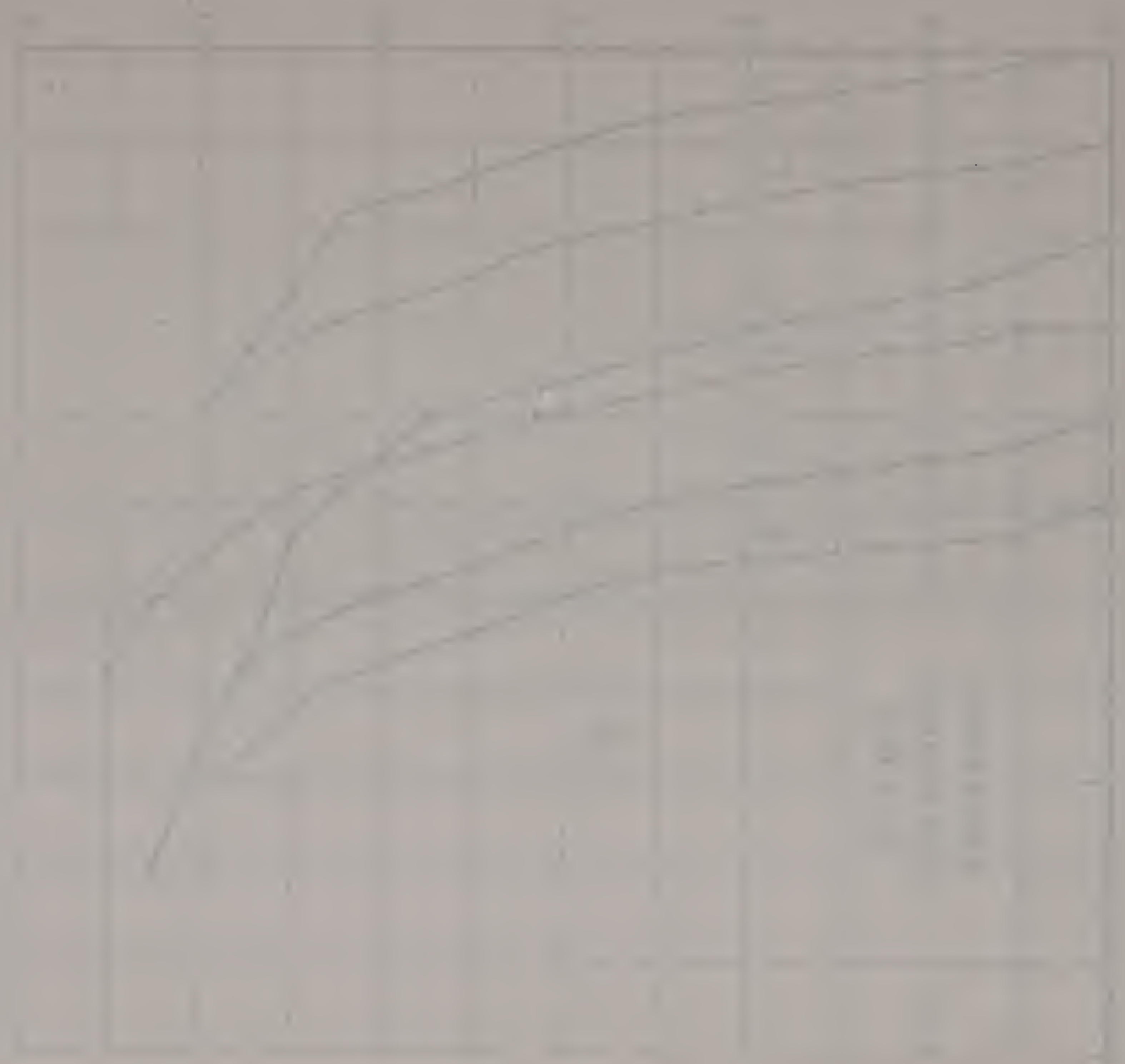


Fig. 5.30
LOAD vs. SLIP
Series-4F6



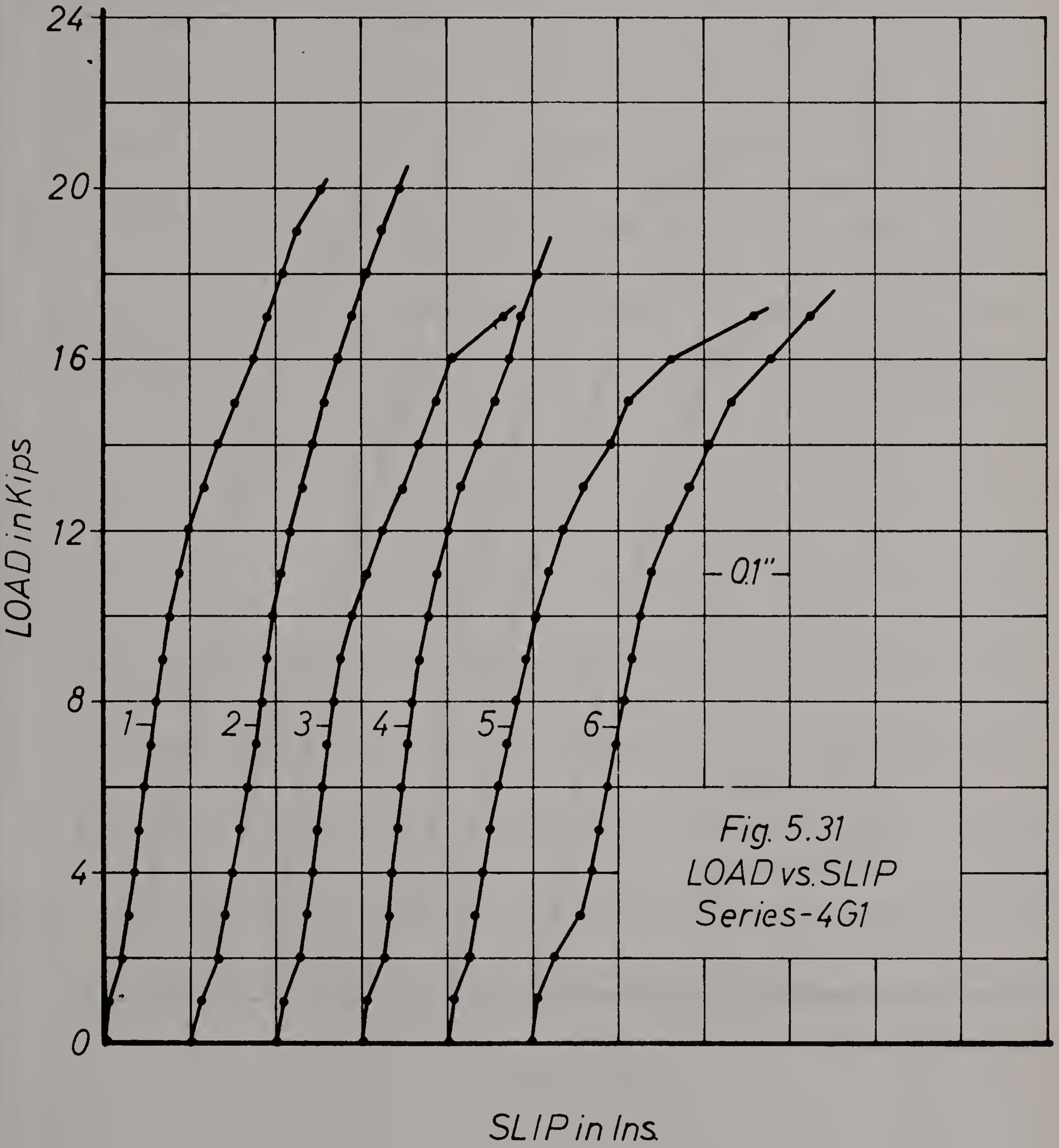


Fig. 5.31
LOAD vs. SLIP
Series-4G1

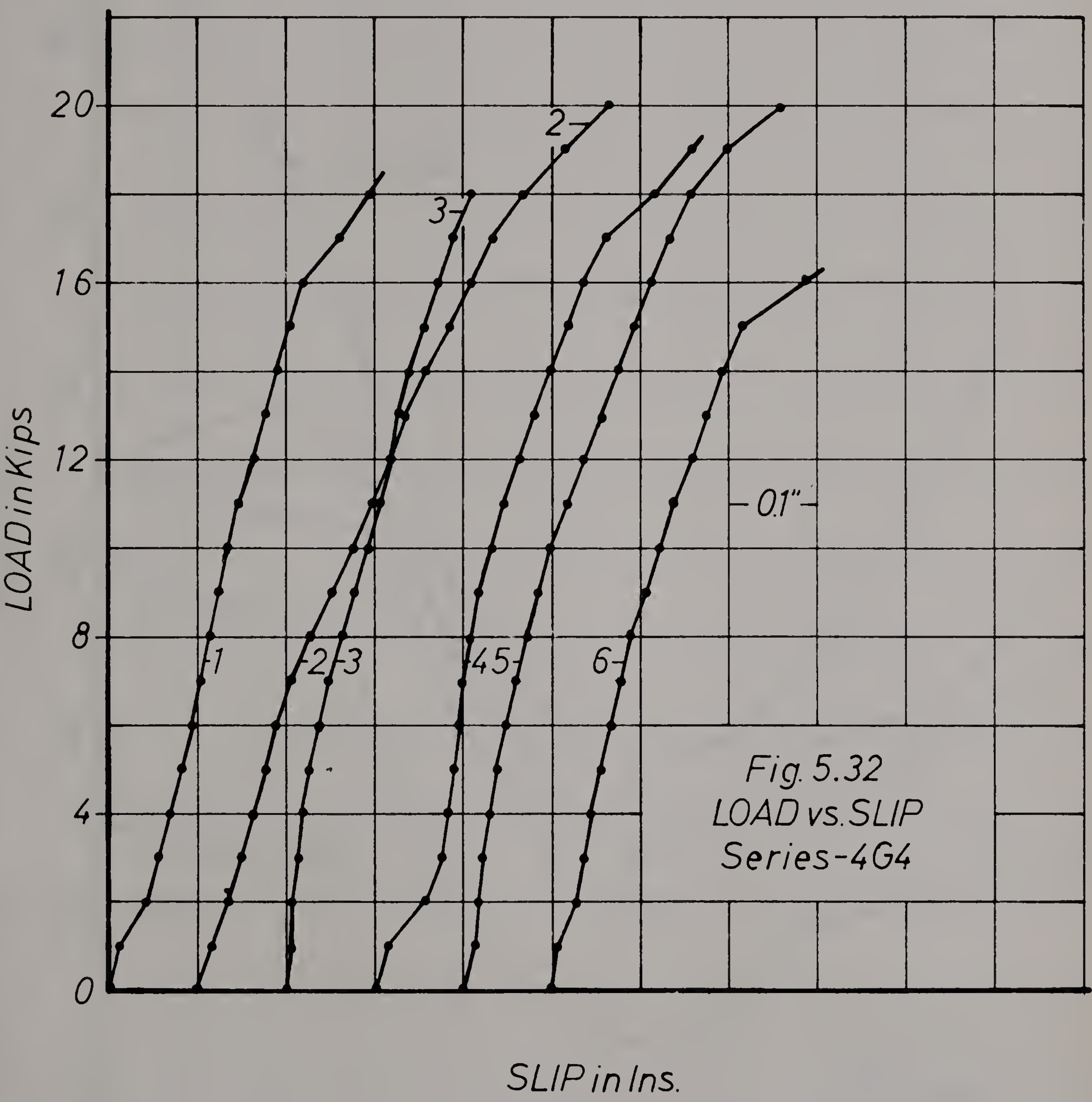


Fig. 5.32
LOAD vs. SLIP
Series-4G4

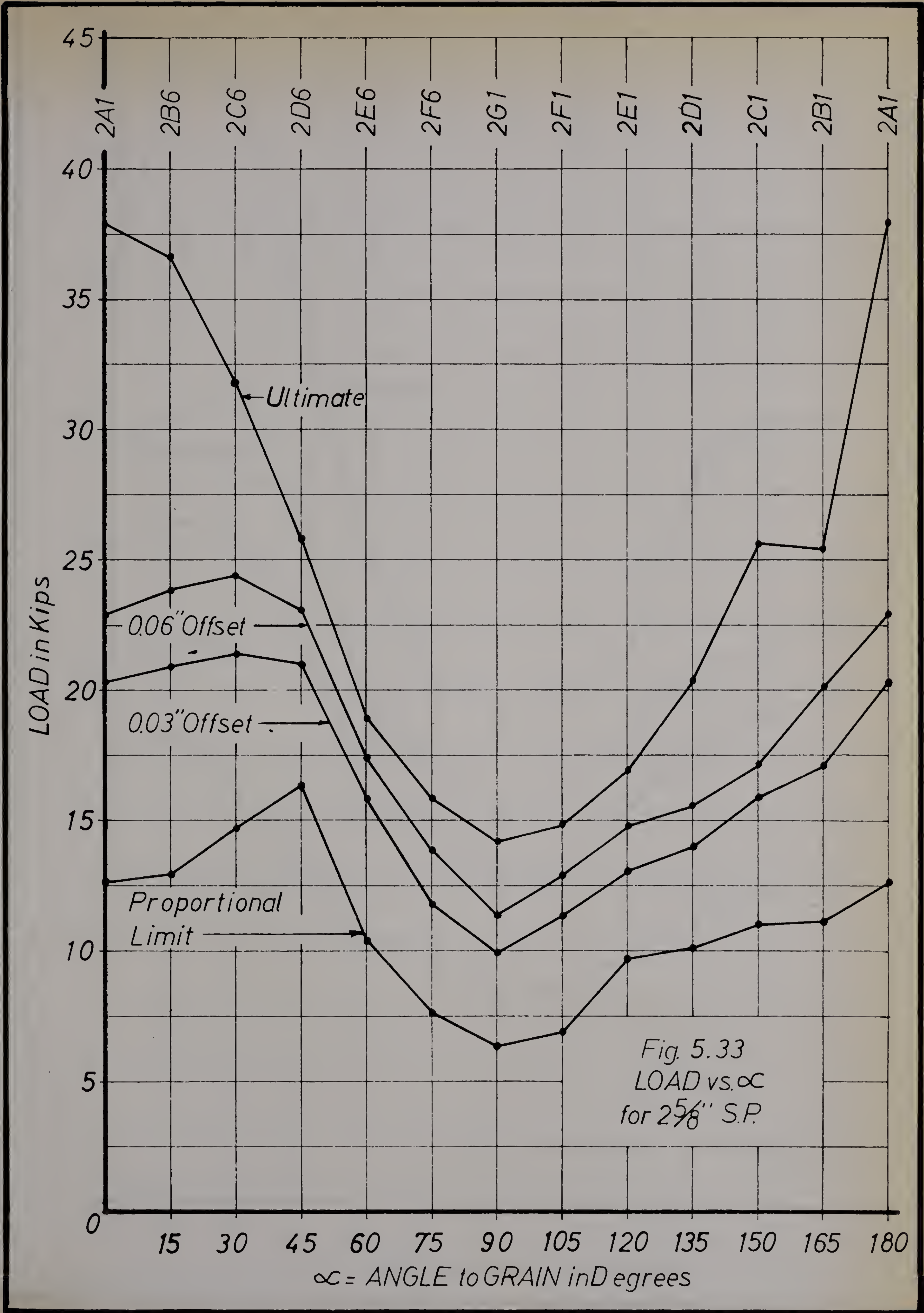


Fig. 5.33
LOAD vs. α
for $2\frac{5}{8}$" S.P.

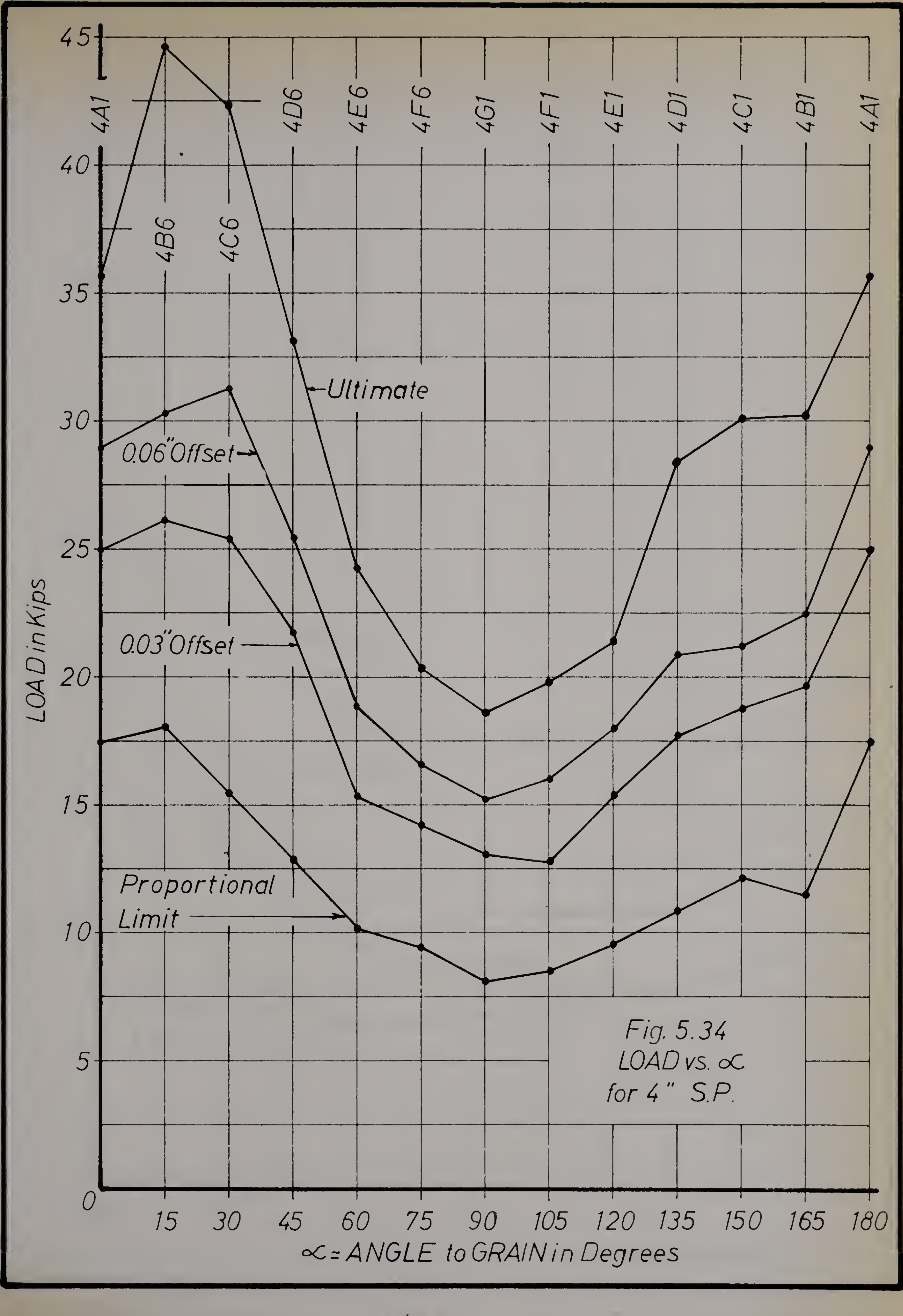


Fig. 5.34
LOAD vs. ∝
for 4" S.P.

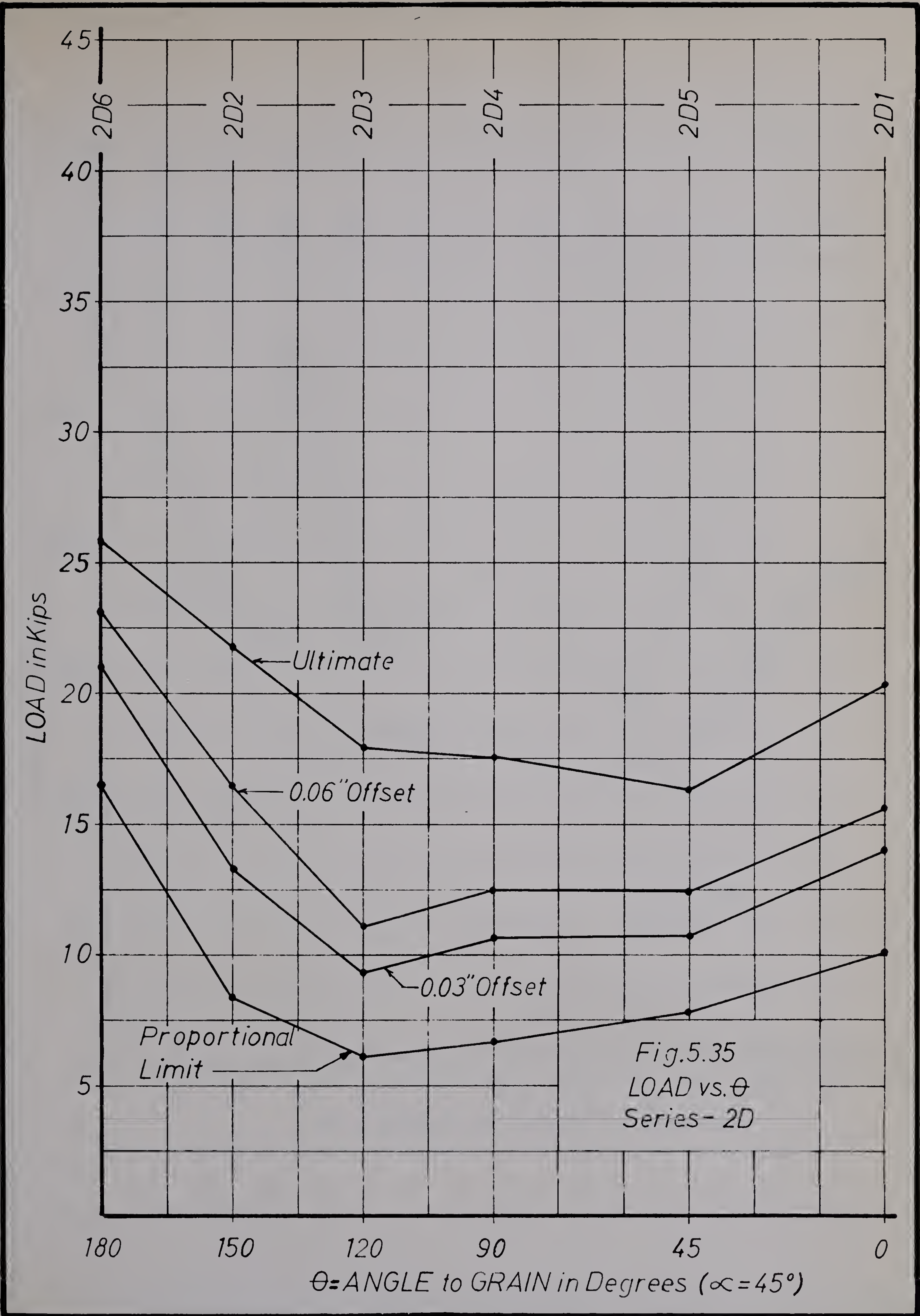


Fig.5.35
LOAD vs. θ
Series - 2D

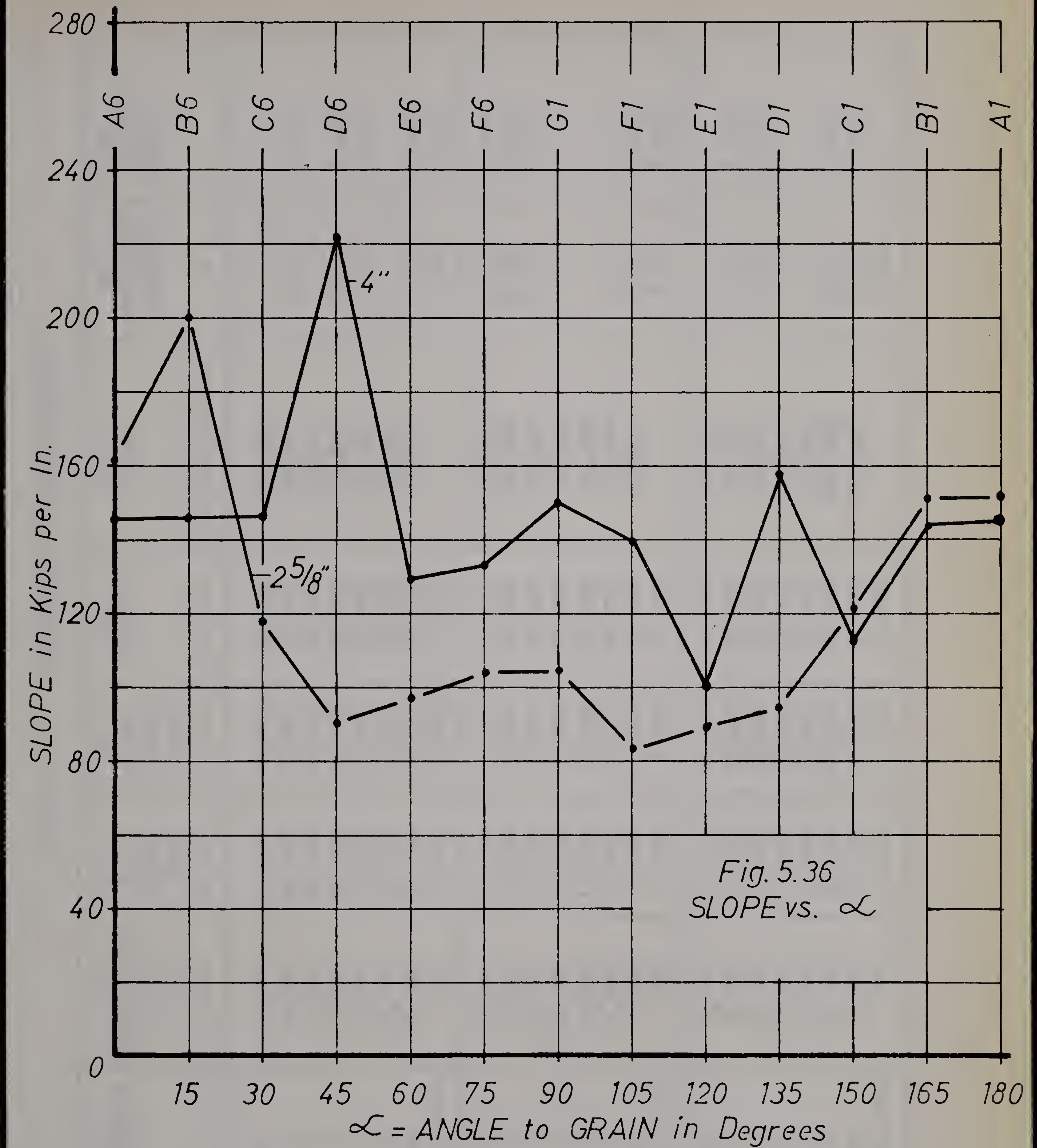


Fig. 5.36
SLOPE vs. ∝

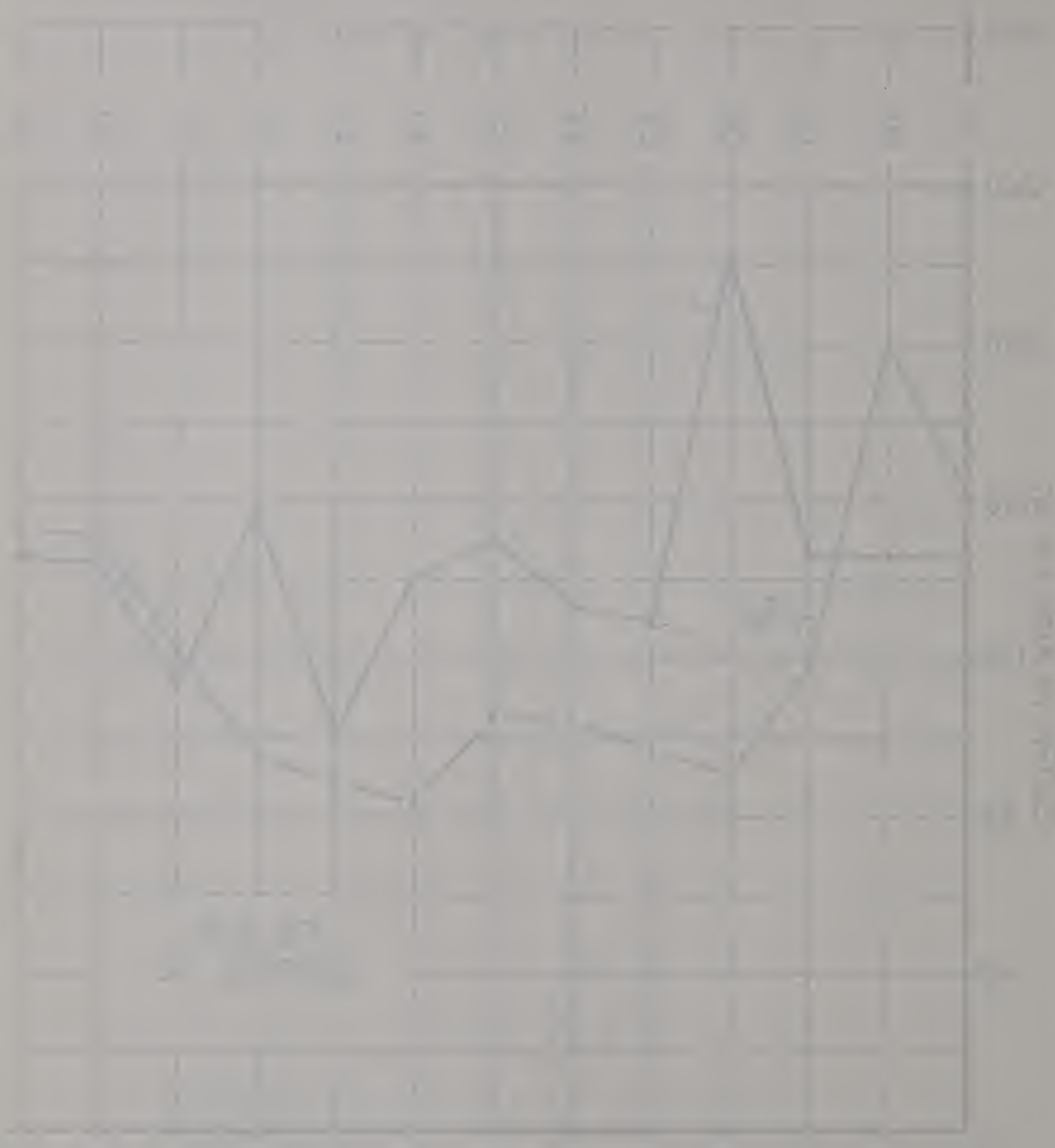


TABLE V - 1   TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs.	(3) 0.03 OFFSET LOAD in lbs.	(4) 0.06 OFFSET LOAD in lbs.	(5) ULTIMATE in lbs.	(6) SLOPE in lbs per in.	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
2A11	11,000	17,600	20,400	33,200	165,000		
2	14,000	24,400	27,000	35,500	155,000	14.19	0.510
3	13,000	20,000	23,200	38,400	182,500		
4	13,000	20,800	22,800	41,000	172,500	15.44	0.440
5	12,000	19,600	21,600	40,000	145,000	17.71	0.447
6	13,000	19,500	22,200	39,500	150,000		
Mean	12,700	20,300	22,900	37,900	161,500	15.78	0.466
Std. Dev.	940	2,060	2,090	2,730		1.46	0.031
2A41	8,000	10,600	12,300	25,000	109,000	13.35	0.494
2	7,500	10,700	12,600	24,200	100,000	13.60	0.496
3	8,500	11,500	13,900	28,100	102,500	13.56	0.513
4	8,400	11,700	13,200	28,000	74,000		
5	8,000	12,000	14,000	23,700	81,500		
6	8,600	13,800	16,200	26,000	11,100		
Mean	8,200	11,700	13,700	25,800	96,500	13.50	0.501
Std. Dev.	380	1,060	1,280	1,740		0.10	0.003
2B11	9,500	16,000	20,000	29,500	177,500		
2	9,000	15,000	19,600	21,800	177,500	14.80	0.462
3	12,000	16,600	19,300	27,500	132,500	15.35	0.486
4	13,000	17,400	18,000	27,500	132,500		
5	14,000	22,000	25,000	27,000	152,000		
6	9,400	15,400	18,900	19.300	194,000	15.72	0.495
Mean	11,200	17,100	20,100	25,400	161,000	15.29	0.481
Std. Dev.	190	2,340	2,270	3,620		0.38	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs.	(3) 0.03 OFFSET LOAD in lbs.	(4) 0.06 OFFSET LOAD in lbs.	(5) ULTIMATE in lbs.	(6) SLOPE in lbs per in.	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
2B61	12,000	22,000	25,300	39,500	184,000	16.86	0.554
2	11,000	20,700	23,700	35,000	135,000		
3	14,600	20,200	22,500	35,500	190,000	14.85	0.429
4	14,000	21,600	24,200	33,800	159,500	17.61	0.513
5	14,000	22,400	25,700	39,100	205,000		
6	12,000	18,900	21,500	36,700	323,000		
Mean	12,900	21,000	23,800	36,600	199,500	16.44	0.499
Std. Dev.	130	1,190	1,470	2,100			
2C11	10,400	14,200	15,600	24,000	139,000		
2	10,200	16,600	18,200	25,100	139,000	18.40	0.419
3	11,500	18,000	19,600	27,600	118,000		
4	10,000	14,400	15,700	26,700	94,000		
5	13,000	17,100	17,700	25,900	132,500	14.50	0.479
6	11,000	15,200	16,300	24,700	104,500	16.83	0.393
Mean	11,000	15,900	17,200	25,700	121,000	16.58	0.430
Std. Dev.	100	1,410	1,450	1,260		1.60	
2C61	14,600	22,000	25,100	33,300	126,000		
2	15,600	21,600	25,200	33,200	91,000		
3	14,200	19,700	22,400	30,500	137,000		
4	15,000	23,100	25,800	30,200	107,000	14.81	0.469
5	15,000	20,700	23,600	32,200	119,500	14.58	0.479
6	14,000	21,200	24,300	31,400	123,000	14.80	0.478
Mean	14,700	21,400	24,400	31,800	117,500	14.73	0.475
Std. Dev.	540	1,060	1,140	1,210		0.10	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs.	(3) 0.03 OFFSET LOAD in lbs.	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE in lbs	(6) SLOPE in lbs per in.	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
2D11	11,000	14,100	16,000	22,200	103,000	18.55	0.426
2	9,400	13,000	15,400	20,700	106,500		
3	11,000	17,700	18,200	19,100	78,000		
4	8,400	11,700	13,500	21,900	99,000		
5	11,000	13,000	14,700	18,700	90,500	17.56	0.448
6	9,800	14,500	15,800	19,500	98,500	15.82	0.470
Mean	10,100	14,000	15,600	20,300	94,500	17.31	0.448
Std. Dev.	990	1,880	1,430	1,580		1.13	
2D21	7,000	11,100	14,400	21,400	101,000	17.75	0.505
2	8,000	12,700	15,700	20,500	140,000		
3	9,000	13,000	16,000	20,900	135,000		
4	9,000	13,300	15,800	21,100	88,000		
5	9,000	17,400	21,100	22,400	109,000	18.13	0.480
6	8,000	12,000	16,000	24,500	141,500	16.94	0.473
Mean	8,300	13,300	16,500	21,800	119,000	17.61	0.486
Std. Dev.	750	1,990	2,130	1,340		0.50	
2D31	5,200	8,600	10,600	19,100	74,000	15.86	0.468
2	7,200	10,500	12,600	17,100	104,000	15.55	0.460
3	6,400	9,500	11,300	17,300	93,000	14.74	0.460
4	5,100	8,800	10,400	18,300	112,000		
5	6,200	9,000	10,800	18,300	119,000		
6	6,600	9,400	10,800	17,400	74,000		
Mean	6,100	9,300	11,100	17,900	96,000	15.38	0.475
Std. Dev.	750	620	730	730		0.47	

TABLE V - 1 (Cont'd) TABULATION OF REST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs.	(3) 0.03 OFFSET LOAD in lbs.	(4) 0.06 OFFSET LOAD in lbs.	(5) ULTIMATE LOAD in lbs.	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
2D41	5,000	10,100	12,100	17,500	87,000	16.85	0.517
2	6,500	10,700	12,200	16,500	73,500		
3	6,200	10,000	12,000	17,700	108,000	15.65	0.475
4	6,000	9,100	11,300	18,300	84,000		
5	5,400	9,900	11,800	17,400	150,000	15.82	0.518
6	11,000	14,100	15,400	17,800	73,000		
Mean	6,700	10,600	12,500	17,500	96,000	16.11	0.503
Std. Dev.	1,990	1,610	1,340	560		0.53	
2D51	7,000	9,400	11,300	17,100	124,500		
2	7,100	10,600	12,300	15,300	97,000		
3	10,100	13,000	13,800	16,500	104,500	14.95	0.496
4	7,100	10,300	12,200	15,200	101,000	13,95	0.455
5	7,400	11,700	14,100	16,200	80.000	14.96	0.475
6	6,500	9,500	10,800	17,500	81,500		
Mean	7,500	10,800	12,400	16,300	98,000	14 62	0.475
Std. Dev.	1,180	1,260	1,200	880		0.48	
2D61	16,400	20,500	22,500	25,400	100,000	17.85	0.416
2	17,000	22,300	24,700	28,400	96,000		
3	17,400	21,400	23,400	27,500	83,500		
4	15,100	20,700	23,300	26,200	89,000	17.52	0.416
5	16,500	21,300	22,700	23,500	93,500	18.43	
6	15,600	19,800	22,000	23,900	77,000		0.458
Mean	16,300	21,000	23,100	25,800	90,000	17.93	0.430
Std. Dev.	780	790	890	1,790		0.38	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs	(3) 0.03 OFFSET LOAD in lbs.	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE LOAD in lbs.	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
2E11	9,600	14,400	17,500	19,100	104,000	16.20	0.573
2	10,100	13,700	15,000	16,500	73,000		
3	9,000	11,700	13,600	17,700	128,000		
4	9,300	12,600	13,900	15,800	78,000	16.37	0.575
5	10,000	13,000	14,700	17,100	69,000	16.55	0.570
6	10,200	13,300	14,100	15,500	82,000		
Mean	9,700	13,100	14,800	17,000	89,000	16.37	0.573
Std. Dev.	440	850	1,300	1,200		0.14	
2E61	10,200	17,000	17,800	18,500	80,000		
2	8,400	14,000	16,800	18,800	92,000	16.54	0.594
3	10,000	15,100	17,200	19,700	84,000	16.05	0.587
4	10,400	16,000	17,300	18,600	110,000		
5	12,000	15,400	17,100	18,900	119,500		
6	11,400	17,600	18,200	18,900	95,000	15.93	0.591
Mean	10,400	15,900	17,400	18,900	97,000	16.17	0.591
Std. Dev.	1,140	1,200	470	400		0.26	
2F11	6,400	11,100	13,300	15,600	83,000	15.00	0.562
2	6,400	11,000	13,000	14,800	97,000		
3	7,000	11,600	12,500	14,100	73,000	14.87	0.543
4	8,000	12,400	14,400	16,700	93,000	14.10	0.547
5	7,000	11,000	12,200	13,500	75,000		
6	6,400	10,800	12,100	14,200	77,000		
Mean	6,900	11,300	12,900	14,800	83,000	14.66	0.551
Std. Dev.	570	540	790	1,090		0.40	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs.	(3) 0.03 OFFSET LOAD in lbs	(4) 0.06 OFFSET LOAD in lbs.	(5) ULTIMATE LOAD in lbs.	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
2F61	7,400	12,000	13,500	16,300	90,000		
2	9,700	12,500	13,300	15,100	102,000		
3	7,400	11,700	14,800	17,000	82,000	13.99	0.550
4	7,300	12,000	14,400	17,200	100,000	15.00	0.550
5	6,200	10,800	11,500	13,800	124,500		
6	8,100	11,600	12,800	15,800	125,500	14.03	0.606
Mean	7,600	11,800	13,400	15,900	104,000	14.34	0.569
Std. Dev.	910	520	1,080	1,200		0.47	
2G11	5,200	8,800	10,300	14,400	86,500		
2	6,100	9,200	9,900	13,900	96,000	14.49	0.442
3	5,200	9,300	10,500	14,500	130,000		
4	6,300	10,200	11,800	12,700	121,000		
5	8,100	11,800	13,500	14,600	132,500	12.12	0.439
6	7,000	10,300	12,200	15,200	6,200	13.92	0.472
Mean	6,300	9,900	11,400	14,200	104,500	13.51	0.451
Std. Dev.	1,020	990	1,260	540		1.01	
2G41	7,200	9,500	10,400	13,100	58,500		
2	6,600	9,300	10,300	12,200	64,500		
3	6,000	8,000	9,600	13,900	92,000	12.98	0.501
4	5,500	9,000	10,200	13,300	62,500	13.49	0.471
5	6,000	8,300	9,400	12,000	71,500	12.99	0.493
6	5,300	8,700	9,600	13,400	68,500		
Mean	6,100	8,800	9,900	13,000	69,500	13.15	0.488
Std. Dev.	640	530	390	690		0.25	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs.	(3) 0.03 OFFSET LOAD in lbs	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE LOAD in lbs.	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
4A11	14,200	21,000	24,400	35,300	144,500		
2	17,000	22,700	26,400	39,700	144,500	16.50	0.504
3	17,200	22,000	26,300	30,400	140,000		
4	17,000	25,200		26,700	111,000		
5	17,200	27,000	33,400	41,700	226,000	15.00	0.452
6	22,000	31,700	34,300	40,100	107,000	16.93	0.528
Mean	17,400	24,900	29,000	35,700	145,500	16.14	0.495
Std. Dev.	2,300	3,630	4,070	5,520		0.83	
4A41	10,000	23,500	24,700	30,200	109,000	11.05	0.485
2	10,300	17,000	20,100	28,400	95,000		
3	10,000	13,500	15,700	32,700	132,500	10.56	0.498
4	12,000	17,000	19,000	33,600	136,500		
5	8,100	10,300		26,500	108,000	14.72	0.560
6	11,000	16,900	19,100	33,000	90,500		
Mean	10,200	16,400	19,700	30,700	112,000	12.11	0.514
Std. Dev.	1,180	4,020	2,900	2,620		1.86	
4B11	13,000	19,400	22,500	33,600	169,500		
2	11,000	17,400	20,200	25,600	200,000	19.55	0.487
3	8,000	15,400	19,600	27,200	129,500	17.49	0.464
4	12,000	22,000	23,500	33,700	102,000		
5	12,000	23,100	25,500	34,000	102,000	17.20	0.468
6	13,000	20,600	23,500	27,400	160,000		
Mean	11,500	19,700	22,500	30,200	144,000	18.08	0.473
Std. Dev.	1,840	2,720	2,130	3,590		1.05	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs	(3) 0.03 OFFSET LOAD in lbs	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE LOAD in lbs.	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
4B61	17,300	28,100	32,600	43,400	92,000		
2	22,000	30,000	34,500	43,300	105,000		
3	21,000	28,500	31,700	43,800	198,000	13.76	0.444
4	23,000	30,000	33,500	44,600	160,000		
5	13,000	21,200	26,100	46,400	192,000	15.31	0.568
6	12,000	19,000	23,300	46,600	128,000	15.78	0.509
Mean	18,100	26,100	30,300	44,700	146,000	14.95	0.507
Std. Dev.	4,310	4,370	4,120	1,360		0.86	
4C11	10,900	18,900	20,500	29,100	98,000	17.20	0.535
2	11,200	17,600	21,000	29,700	117,500		
3	9,400	15,600	18,300	31,800	120,000	17.31	0.536
4	9,400	16,500	20,600	30,900	100,000		
5	16,000	19,500	21,200	30,900	106,000		
6	16,000	24,500	25,800	28,200	133,500	15.08	0.476
Mean	12,200	18,800	21,200	30,100	112,500	16.53	0.516
Std. Dev.	2,810	2,890	2,250	1,240		1.03	
4C61	19,000	32,000	36,800	42,300	183,500	15.70	0.584
2	14,400	24,000	33,000	42,700	150,000	15.20	0.498
3	16,000	23,000	26,000	40,000	152,000		
4	13,500	26,400	36,200	45,700	104,000	15.83	0.498
5	16,000	26,000	30,900	42,000	132,000		
6	14,000	21,000	24,700	41,000	157,000		
Mean	15,500	25,400	31,300	42,300	146,500	15.58	0.527
Std. Dev.	1,840	3,460	4,640	1,790		0.26	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs	(3) 0.03 OFFSET LOAD in lbs	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE LOAD in lbs	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
4D11	10,000	16,200	19,000	33,000	157,000	15.15	0.483
2	9,600	16,000	19,400	28,200	197,000	14.25	0.485
3	12,000	20,400	22,200	27,600	146,000		
4	13,000	20,700	25,300	28,200	146,000		
5	11,000	16,400	19,000	26,800	146,000		
6	9,400	16,700	20,400	26,600	154,000	14.65	0.490
Mean	10,800	17,700	20,900	28,400	157,500	14.68	0.486
Std. Dev.	1,310	2,010	2,270	2,180		0.37	
4D61	11,000	19,600	22,800	31,900	277,000	13.42	0.479
2	13,000	22,000	25,000	34,200	183,000		
3	12,500	25,700	29,100	33,400	236,000	13.93	0.476
4	13,500	20,800	23,800	30,800	237,000		
5	13,500	21,500	27,000	34,900	158,000	13.06	0.487
6	13,500	20,800	24,800	33,300	240,000		
Mean	12,800	21,700	25,400	33,100	222,000	13.47	0.481
Std. Dev.	900	1,920	2,090	1,380		0.36	
4E11	9,000	15,000	19,300	21,300	113,000	15.95	0.474
2	9,000	13,400	15,900	21,500	113,000	16.51	0.461
3	9,000	12,600	15,200	20,300	82,000		
4	10,000	15,800	16,700	21,300	102,000		
5	12,000	17,500	19,800	21,400	111,000		
6	8,400	18,000	21,300	22,600	79,000	17.42	0.488
Mean	9,600	15,400	18,000	21,400	100,000	16.63	0.474
Std. Dev.	1,190	1,970	2,230	690		0.60	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs	(3) 0.03 OFFSET LOAD in lbs	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE LOAD in lbs	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
4E61	11,000	16,400	19,400	25,700	142,000		
2	10,000	15,500	17,700	24,100	158,000		
3	9,200	14,000	18,800	25,000	111,500	16.82	0.479
4	11,000	15,100	18,600	23,900	118,000		
5	9,000	14,000	18,000	21,200	126,000	17.52	0.504
6	11,000	17,000	20,400	25,500	117,000	16.86	0.486
Mean	10,200	15,300	18,800	24,200	129,000	17.07	0.490
Std. Dev.	860	1,120	900	1,520		0.32	
4F11	8,400	11,500	14,200	19,900	209,000		
2	7,600	11,200	14,100	19,900	146,000	19.02	0.511
3	8,000	13,000	16,000	21,800	182,000	18.83	0.503
4	10,000	13,000	16,700	19,200	101,500		
5	8,000	14,700	17,000	18,100	100,000		
6	9,000	13,700	18,200	19,900	98,000	18.93	0.505
Mean	8,500	12,900	16,000	19,800	139,500	18.93	0.506
Std. Dev.	800	1,210	1,480	1,110		0.14	
4F61	10,000	12,900	16,100	19,900	152,500	15.16	0.478
2	11,500	15,300	18,000	19,900	98,000		
3	8,000	15,000	16,000	19,100	100,500		
4	10,000	16,600	18,800	22,000	109,000	18.70	0.494
5	8,000	12,700	15,700	21,200	138,500	19.42	0.495
6	9,000	12,700	15,000	19,500	198,000		
Mean	9,400	14,200	16,600	20,300	133,000	17.76	0.489
Std. Dev.	1,740	1,520	1,340	1,030		1.86	

TABLE V - 1 (Cont'd) TABULATION OF TEST RESULTS

(1) SPECIMEN	(2) PROPORTIONAL LIMIT LOAD in lbs	(3) 0.03 OFFSET LOAD in lbs	(4) 0.06 OFFSET LOAD in lbs	(5) ULTIMATE LOAD in lbs	(6) SLOPE in lbs per in	(7) MOISTURE CONTENT %	(8) SPECIFIC GRAVITY
4G11	6,000	13,300	15.400	20.200	175,000	11.57	0.471
2	10,000	15,200	17,900	20,500	160,000	12.66	0.481
3	8,000	11,800	13,700	17,300	168,000		
4	8,500	13,300	15,700	18,800	167,000	12,41	0.477
5	6,000	12,000	13,700	17,200	124,000		
6	10,000	13,000	15,000	17,600	105,000		
Mean	8,100	13,100	15,200	18,600	150,000	12.21	0.476
Std. Dev.	1,640	1,090	1,420	1,360		0.47	
4G41	11,000	16,300	17,300	18,500	96,500		
2	7,000	10,500	14,500	20,000	72,000	15.98	0.431
3	7,000	17,400		18,100	88,500	15.78	0.458
4	9,000	12,700	15,700	19,300	124,000		
5	7,000	12,600	16,000	20,000	95,000	13.82	0.537
6	8,200	13,700	15,700	18,700	88,000		
Mean	8,200	13,700	15,700	18,700	94,000	15.19	0.475
Std. Dev.	1,460	2,610	930	1,280		0.97	

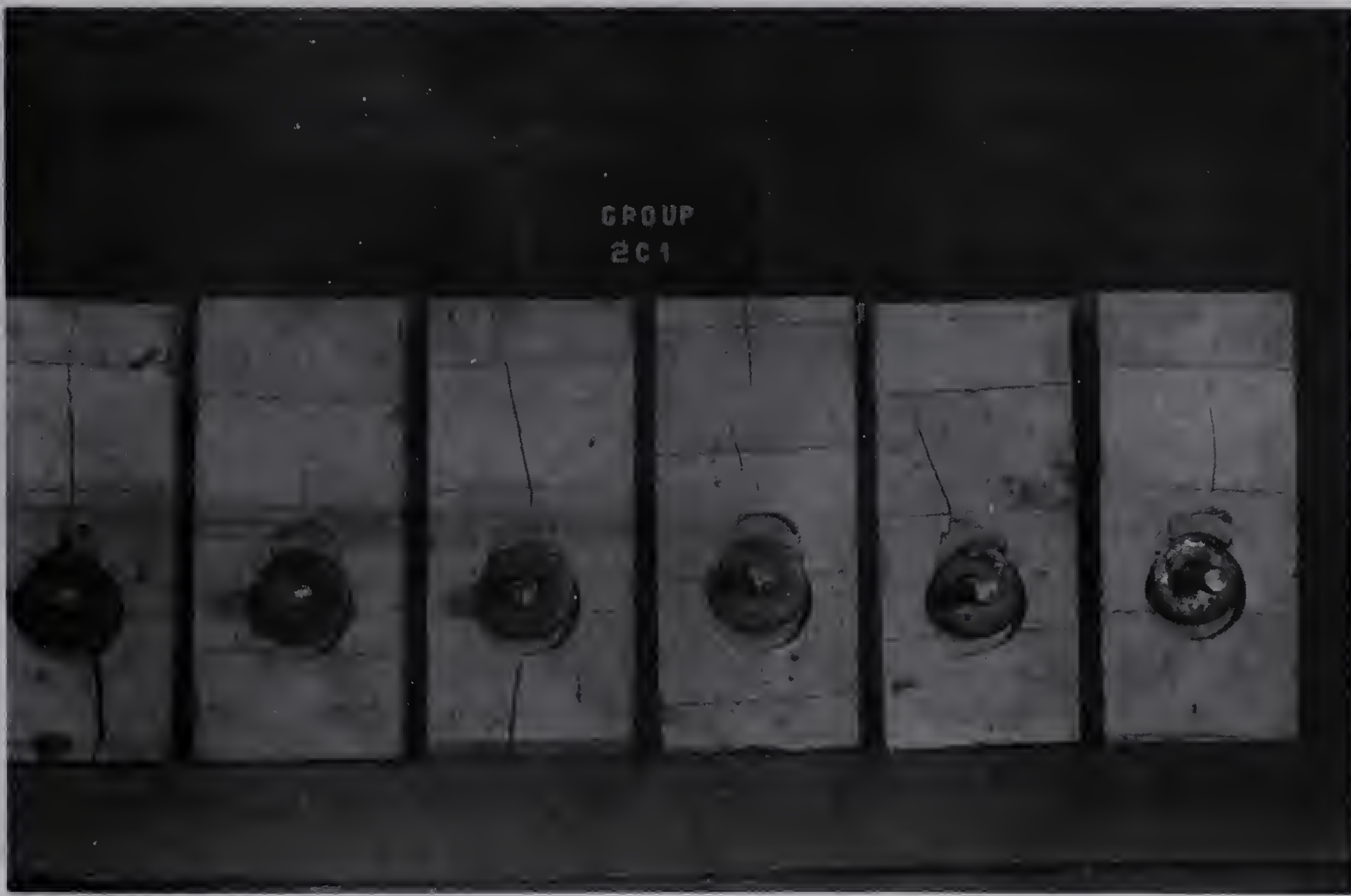


FIGURE 5.37

GROUP 2C1 SPECIMENS AFTER LOAD TESTING

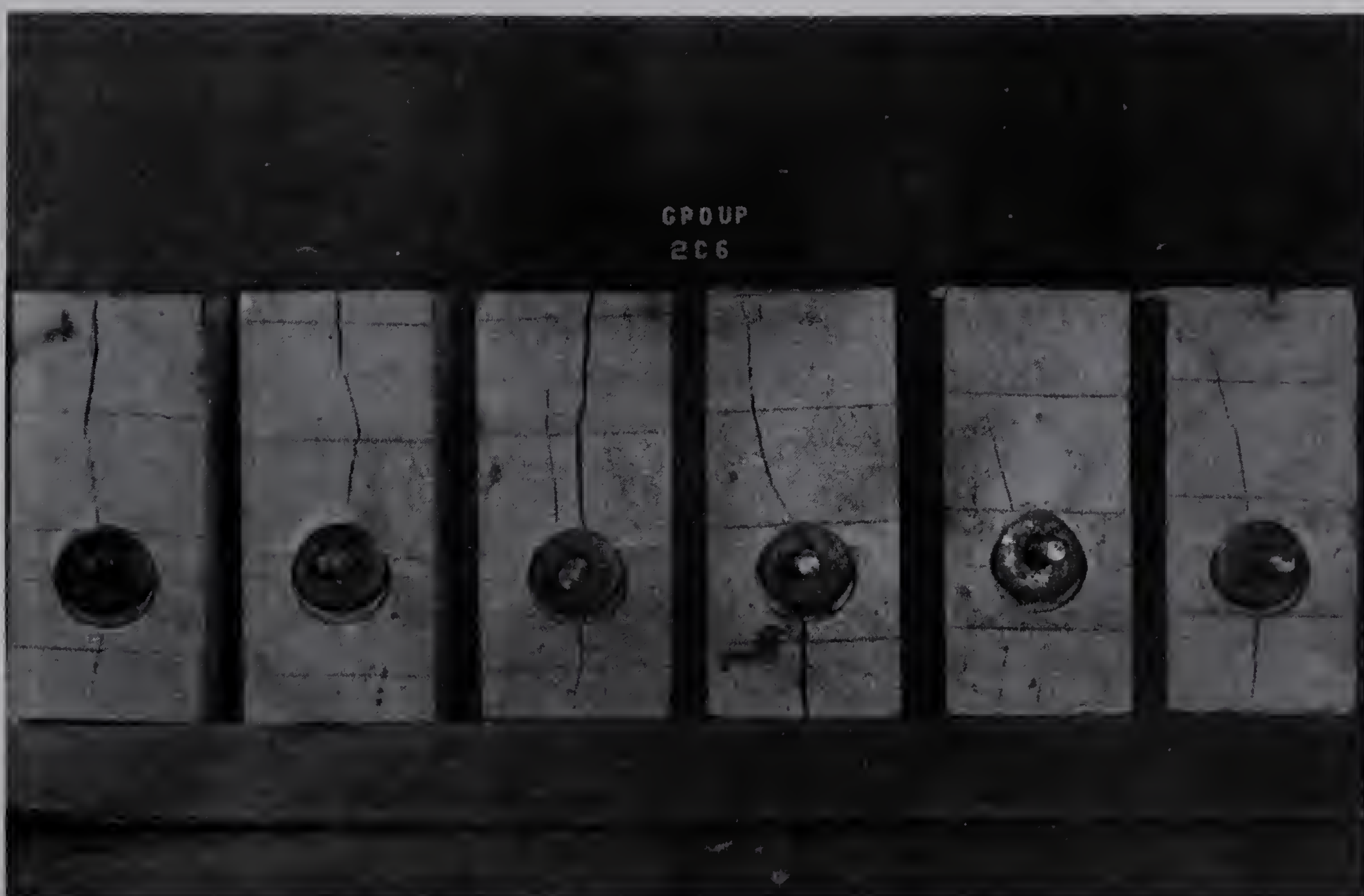
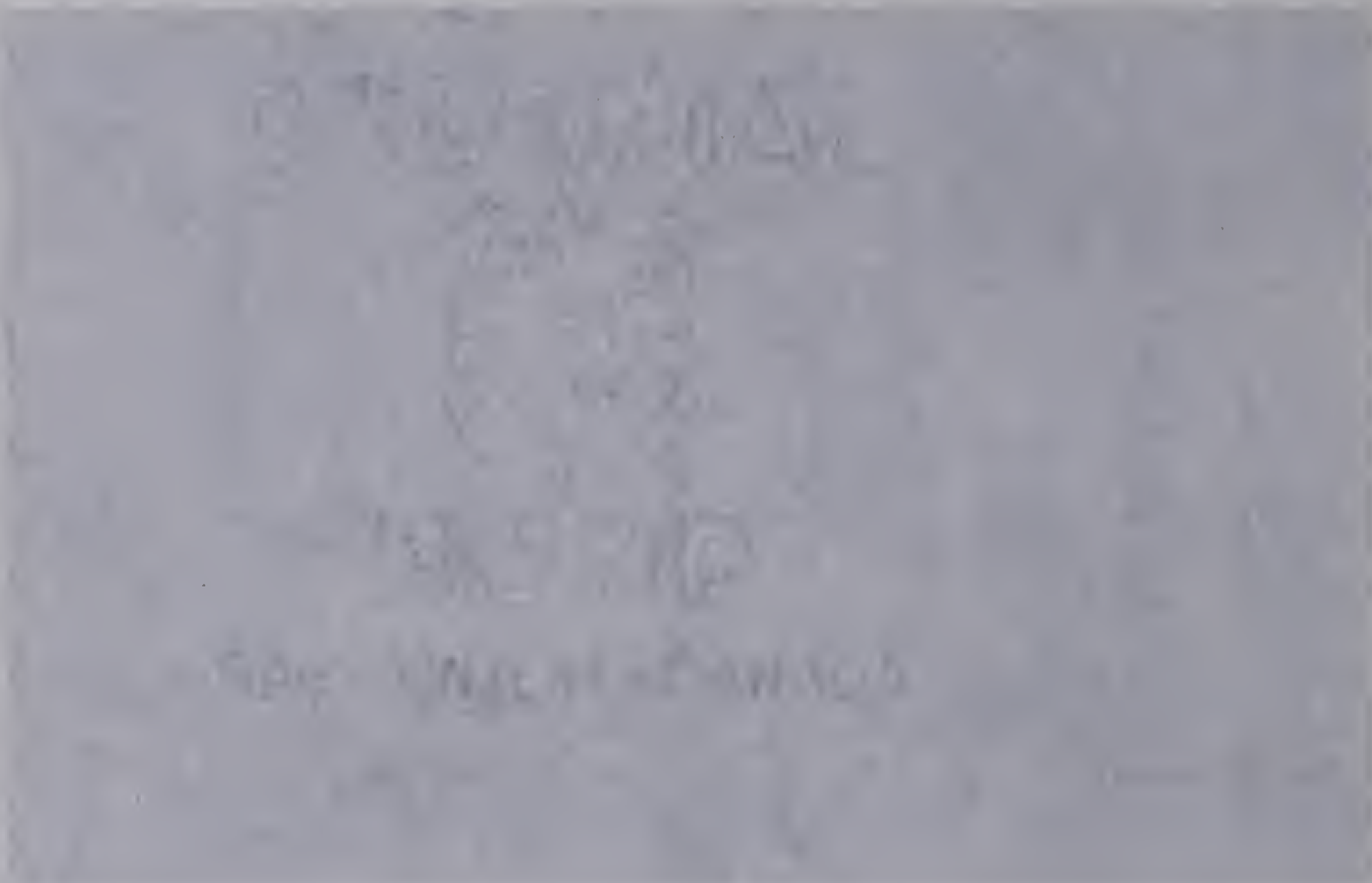


FIGURE 5.38

GROUP 2C6 SPECIMENS AFTER LOAD TESTING



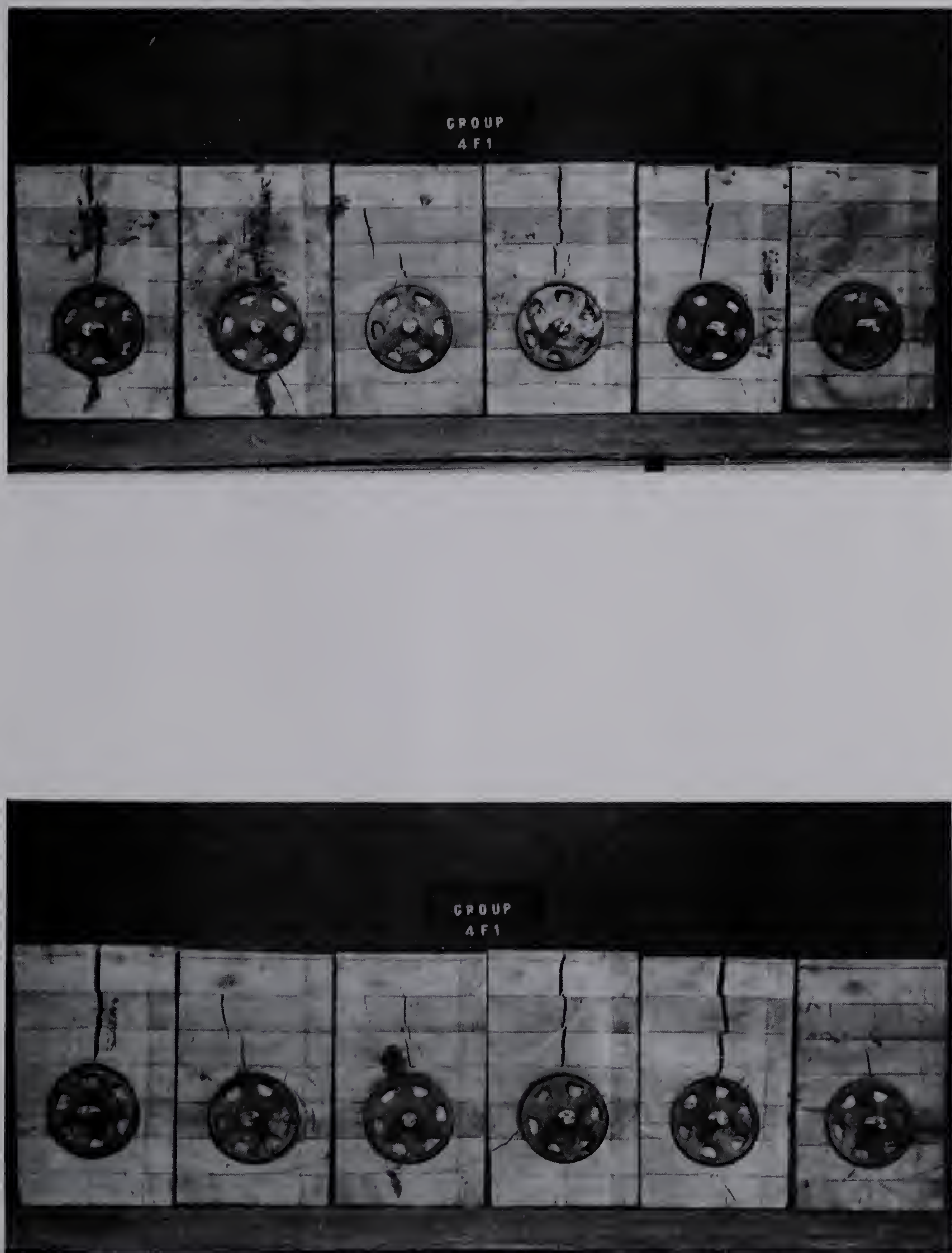


FIGURE 5.39

GROUP 4F1 SPECIMENS AFTER LOAD TESTING

FIGURE 5.40

GROUP 4F6 SPECIMENS AFTER LOAD TESTING

FIGURE 5.41

2-5/8 INCH SHEAR PLATES AFTER LOAD TESTING

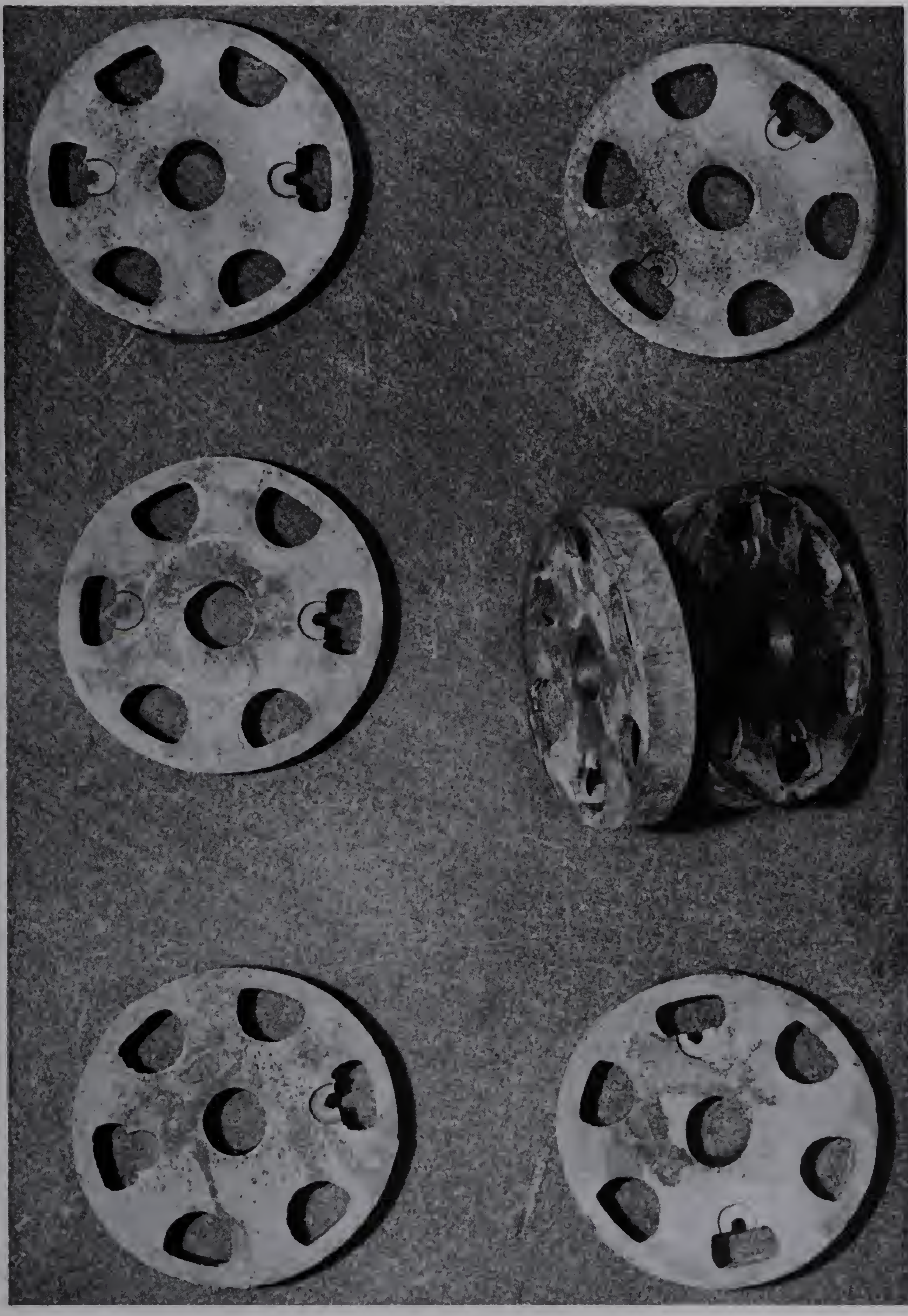


FIGURE 5.42

4 INCH SHEAR PLATES AFTER LOAD TESTING

FIGURE 8.43
BOLTS AFTER LOAD TESTING

CHAPTER VI

DISCUSSION

6.1 Load Slip Curves.

The load slip curves exhibited the normal load versus slip relationship: i.e. as load was applied slip remained proportional to load up to a point at which slip increased at a greater rate than did load, followed by failure. The curves obtained followed this pattern with one major exception, a zone of initial slip was noted as in Figure 6.1. This slip was most likely due to a taking up of the slack in the joint assembly. Minor variations from the theoretical load-slip relationship were likely due to flaws in the specimens.

The proportional limit, the point at which slip is no longer proportional to load, is rather difficult to define in a material such as wood. The proportional limit was considered to be the initial departure of the curve from a straight line drawn through that portion of the curve immediately after the zone of initial slip. The proportional limit may be difficult to define. For this reason it may be desirable to also study loads producing certain offset slips. For the purposes of this investigation loads were established for offset slips of 0.03 inches and 0.06 inches as indicated in Figure 6.1.

6.2 Load vs Grain Angle.

Mean results obtained from the load-slip curves are summarized in Figure 5.33 for 2-5/8 inch shear plates and in Figure 5.34

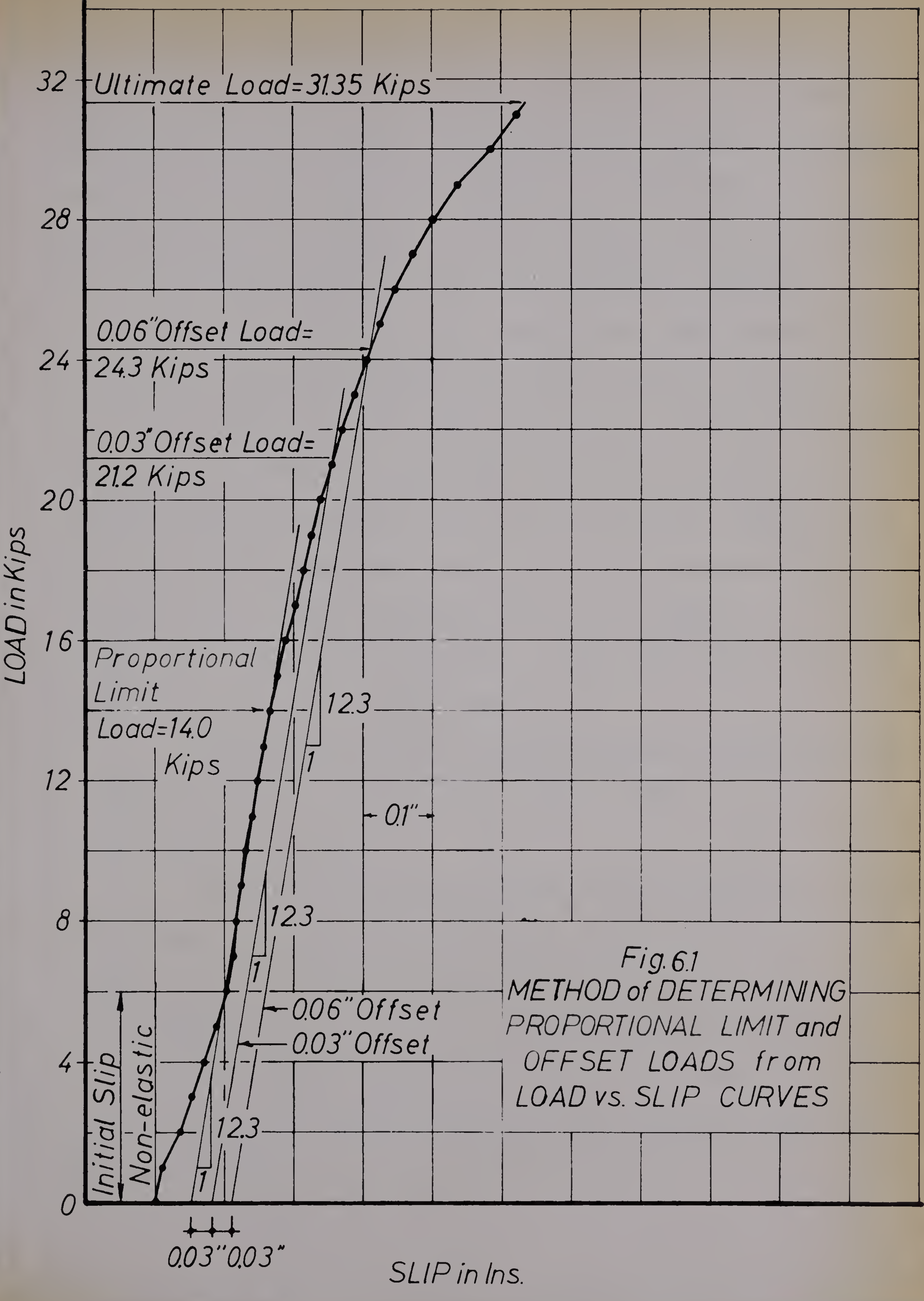


Fig. 6.1
METHOD of DETERMINING PROPORTIONAL LIMIT and OFFSET LOADS from LOAD vs. SLIP CURVES

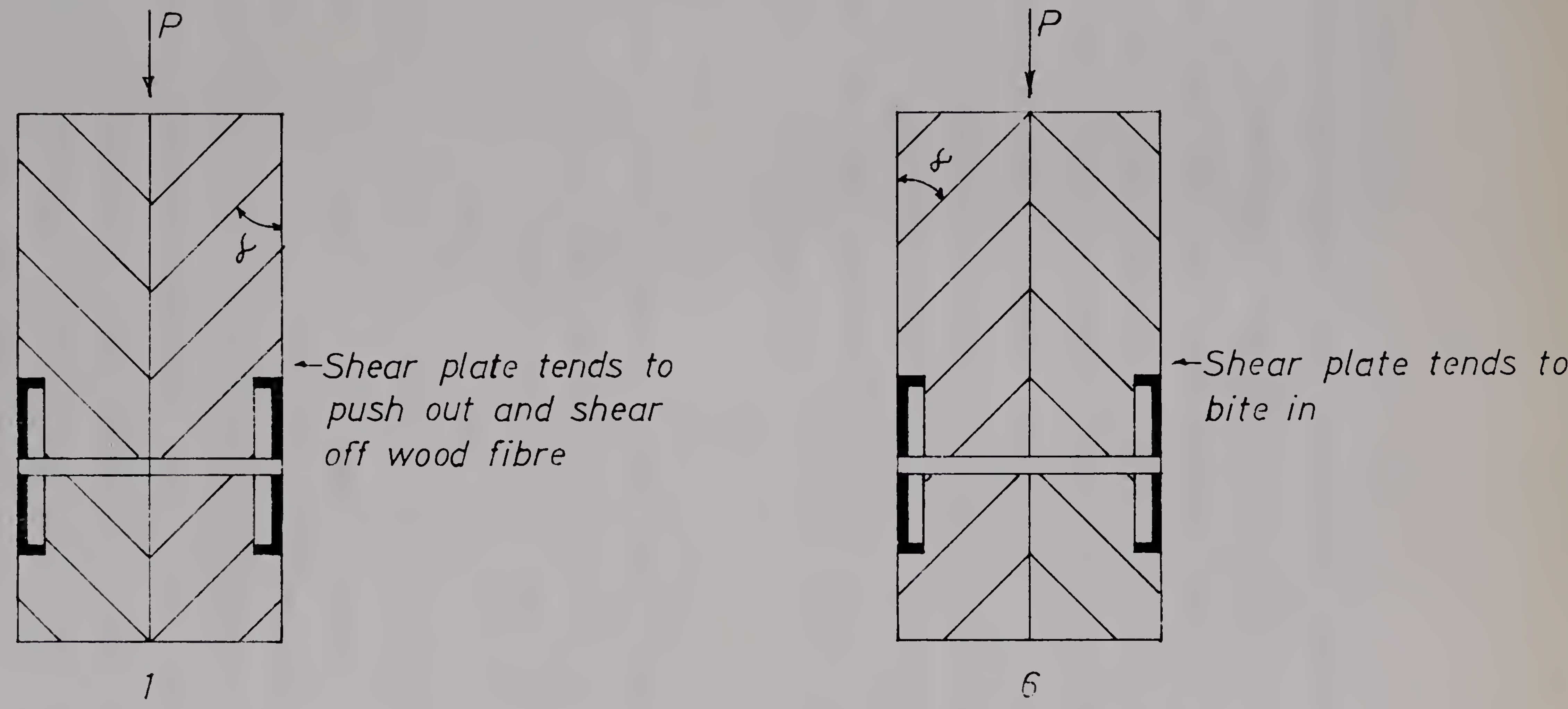
for 4 inch shear plates. In general, as the grain angle α is increased from 0° to 90° the load decreases and as the grain angle α is increased from 90° to 180° the load increases. However, an increase in proportional limit load was noted for group 2 specimens as α increased from 0° to 45° and for group 4 specimens as α increased from 0° to 30°. The ultimate load for group 4 specimens increased as α increased from 0° to 15°. This phenomenon was likely caused by a "locking-in" action of the shear plate into the grain of the wood as shown in Figure 6.2. Since the 2-5/8 inch shear plates are shallower and smaller, and therefore more easily embedded into the grain, this phenomenon was more apparent in the group 2 specimens. Figures 5.37 to 5.40 inclusive verify this behaviour. For the specimens with load angle θ equal to 180°, the shear plates tend to wedge into the specimens whereas for specimens with load angle θ equal to 0° the wood tended to shear off immediately above the shear plates.

The variation of load with grain angle α is non-linear, with a minimum load value at grain angle α equal to 90°.

6.3 Load vs Load Angle.

These curves were similar to the load vs grain angle α curves except that the minimum load values were not as well defined. The minimum ultimate load value occurred at load angle θ equal to 135° while the minimum proportional limit load value occurred at load angle θ equal to 60° as shown in Figure 5.35. Minimum load values for 0.03 inch offset slip and the 0.06 inch offset slip also occurred at load angle θ equal to 60°.

Fig. 6.2 "LOCKING-IN" ACTION OF SHEAR PLATES



Specimen 6 has higher strength characteristics than specimen 1.

6.4 Slope vs Grain Angle.

The variation of the slope of the load-slip curves with the grain angle α is summarized in Figure 5.36. The curve obtained for the 2-5/8 inch shear plates seems to follow quite closely the general shape of the load vs grain angle curves, while that for the 4 inch shear plates bears little or no resemblance to the load vs grain angle curves. It might be expected that the slope vs grain angle curves should exhibit the same general shape as the load vs grain angle curves. The author has no explanation for the marked deviation exhibited by the specimens with 4 inch shear plates and therefore can draw no conclusions from this aspect of the investigation.

6.5 Failure Modes.

Failures in general seemed to follow a specific pattern; i.e shearing of the wood fibres enclosed by the shear plate followed by crushing of the wood immediately above the bolt and/or shear plate and finally splitting induced by the bearing action of the bolt. Excessive bending of the bolts was noted for specimens which had high ultimate loads. In some cases the bolts broke at the root of the threads (Figure 5.43). This occurred only for specimens which had extremely high ultimate loads. Specimens in groups 2A4 and 4A4 failed due to excessive compression perpendicular to the grain since the load was applied at 90° to the grain. Some damage of the shear plates due to bearing was noted (Figures 5.41 and 5.42). Again, this occurred for only the very heavily loaded specimens.

6.6 Criticism of Test Procedure.

Although fairly rigid controls were applied during the testing program certain hind-sight criticisms can now be leveled. The test program was scheduled in accordance with the fabrication of specimens. This led to the testing of partial groups of specimens. Since it was desirable to photograph the specimens as a group considerable time might elapse between the load test and the moisture content and specific gravity test. During this time the moisture content could change appreciably. Only three moisture content and specific gravity specimens were taken for each group of six specimens. The average strength results for the group were obtained, and corrected with the average moisture content and specific gravity results for the group.

Had all specimens been fabricated at one time and if storage facilities with constant temperature and humidity had been readily available the problem of varying moisture content could have been avoided. If moisture content and specific gravity determinations had been made for each specimen, more accurate corrections for these variables could have been made.

6.7 Effect of Specific Gravity and Moisture Content Variations.

The effects of varying specific gravity and moisture content upon test results are shown in Appendices A and B.

If the procedure outlined in Appendix A is applied to the mean proportional limit load of specimen group 2E6, which has the greatest deviation from the base value of 0.48, the maximum expected variation due to specific gravity can be calculated.

$$S = S_1 \times \left(\frac{g}{g_1} \right)^{1.25}$$

$$= 10{,}400 \times \left(\frac{0.480}{0.591}\right)^{1.25}$$

S = 8040 lbs or 77.3% of test value.

If the procedure outlined in Appendix B is applied to the mean proportional limit load of specimen group 4F1, which has the greatest moisture content deviation from the base value of 15%, the maximum expected variation due to moisture content can be calculated.

$$\text{Log } S_3 = \log S_2 + (M_2 - M_3) \, \frac{\log\left(\frac{S_{12}}{S_g}\right)}{(Mp-12)}$$

$$= \log 8500^{*} + (18.93 - 15.00) \, \frac{\log 1.94^{**}}{(24 - 12)}$$

S_3 = 10,300 lbs or 121.2% of test value.

*load was not previously corrected for specific gravity as shown in Appendix B.

$**\frac{S_{12}}{S_g}$ = 1.94 (See Figure B-1)

It is evident from the calculations that the effect of varying specific gravity and moisture content can be appreciable. Although it might appear from the previous calculations that the combined effect might produce up to a 40% change in load values obtained from test results, it is more likely that maximum variations in the order of 10% to 15% would prevail. Since the formulae used for specific gravity and moisture content corrections are empirical and since insufficient moisture and specific gravity data was available it was decided not to adjust the

test results .

6.8 Simplified Trend Curves.

For the purpose of expressing the trend of the results obtained two types of trend curves will be examined:

1. a parabolic curve fitted between loads obtained for grain angle values of 9° and 90°.
2. a "Hankinson's Type" curve fitted between loads obtained for grain angle values of 0° to 90°.

These curves are shown for ultimate load and for proportional limit load results for the 4" shear plates only. (Figure 6.3). It is evident that no account is taken in these simplified equations of the "locking-in action" exhibited by some specimens . It appears that either of these simplified curves could be used to establish a lower bound for the ultimate or proportional limit loads based on test test results for values of 0° and 90°.

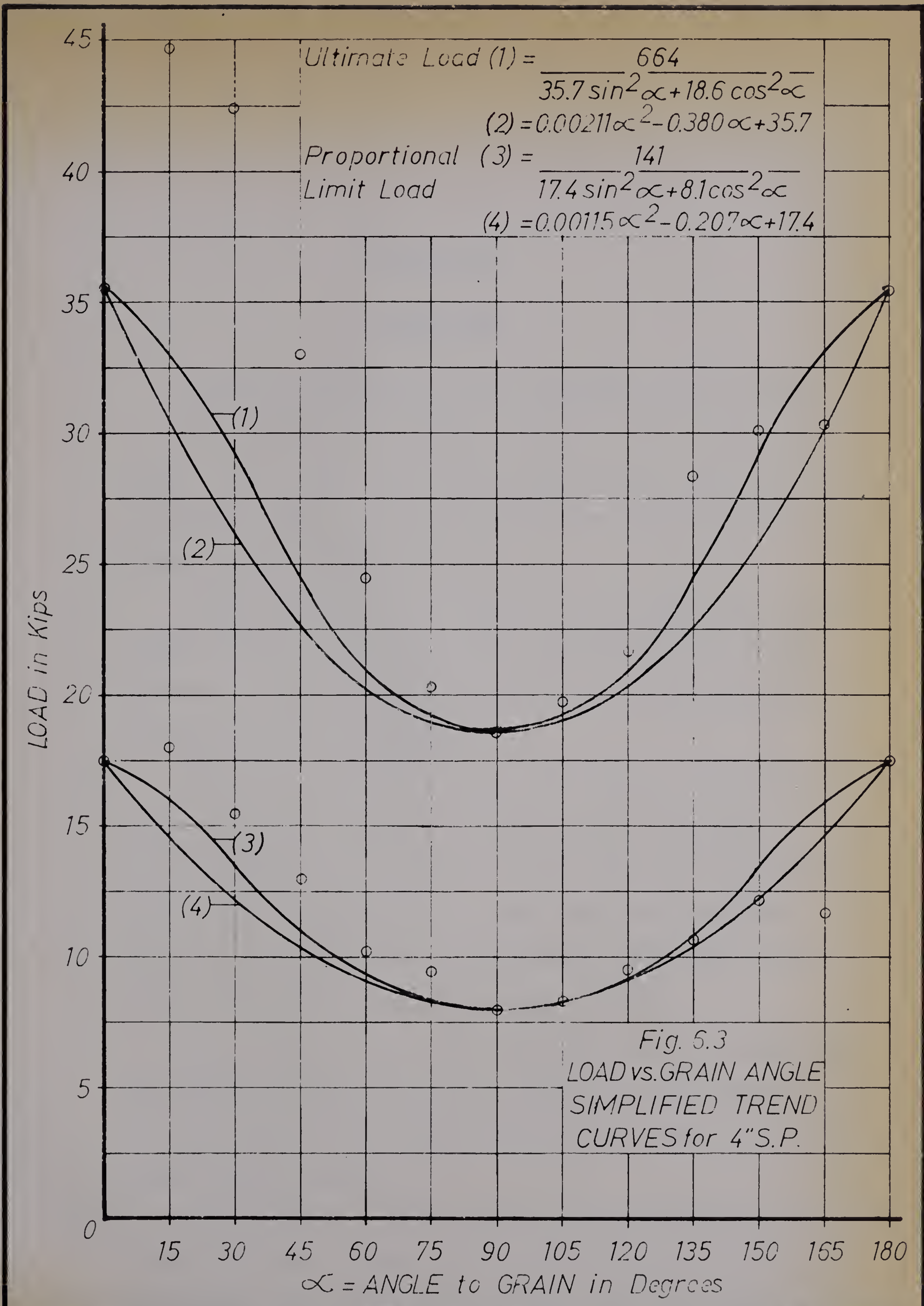


Fig. 6.3
LOAD vs. GRAIN ANGLE
SIMPLIFIED TREND
CURVES for 4" S.P.

CHAPTER VII

CONCLUSIONS

The major conclusions of this investigation are as follows:

1. The strength of shear plate connections varies with grain angle. The strength in general is reduced as the grain angle is is increased from 0° to 90°, and increases as the grain angle is further increased from 90° to 180°.

2. If the specimen is fabricated so that the shear plates tend to wedge into the wood material, higher strengths will be realized than if the specimen is fabricated so that the shear plates tend to shear away the wood material.

3. The effect of the grain angle on the slope of the load-slip curves was not well defined. For the specimens containing 2-5/8 inch shear plates the Slope vs Grain Angle curve was of the same general shape as the Load vs Grain Angle curve while the Slope vs Grain Angle curve for the specimens containing 4 inch shear plates did not follow any particular pattern.

4. The strength of shear plate connections varies with load angle. The strength was reduced as the load angle was varied from 0° to 60° then remained fairly constant up to a load angle of 135° after which it again increased.

5. Simplified trend curves based on a parabolic equation or a "Hankinson's Type" equation may be used to establish a lower bound for ultimate loads and proportional limit loads for varying grain angle.

BIBLIOGRAPHY

(1) National Building Code of Canada, Section 4.3.10.

(2) British Columbia Lumber Manufacturers Association, 1959. Standard Grading and Dressing Rules for Lumber, British Columbia Lumber Manufacturers Association, Vancouver, B.C.

(3) Wood Handbook, No. 72. U. S. Department of Agriculture - Forest Products. Laboratory - Forest Service.

(4) Technical Bulletin No. 865 - United States Department of Agriculture, Washington D.C. Timber-Connector Joints; Their Strength and Design - by John A. Scholten.

(5) Timber Construction Manual. Canadian Institute of Timber Construction.

APPENDIX A

SPECIFIC GRAVITY CORRECTION

A.1 Effect of Specific Gravity on Strength.

Wood is a cellular material, composed of a relatively dense material with a specific gravity of about 1.5. However this material forms cell cavities which may contain air or water. Variations in the size of these cavities and in the thickness of the cell walls cause some species to have more wood substance than others and therefore to have higher specific gravity values. Specific Gravity thus is an excellent index of the amount of wood substance a piece of dry wood contains and hence is an index of its strength properties.

A.2 Specific Gravity Correction.

Any variation in the specific gravity between the specimens tested must therefore be accounted for. The following formula from the Wood Handbook (3) to adjust the strength values obtained in the tests:

$$\frac{S}{S_1} = \left(\frac{g}{g_1}\right)^n$$

where: S = property at specific gravity g,

S_1 = property at specific gravity g_1,

$n = 1.25$

All values were corrected to a constant specific gravity of 0.48 which is average for Douglas Fir.

As an example, the correction for specimen 2A1 for the 0.03 offset load would be computed as follows:

0.03 offset load = 20,300 lbs (from data)

Mean specific gravity = 0.466

$$S = S_1 \times \left(\frac{g}{g_1} \right)^{1.25} = 20{,}300 \times \left(\frac{0.48}{0.466} \right)^{1.25}$$

$$= 20{,}317 \times 1.038 = 21{,}100 \text{ lbs.}$$

APPENDIX B

MOISTURE CONTENT CORRECTION

B.1 Effect of Moisture Content on Strength.

Wood increases in strength as it drys.(3) For small, clear pieces, the strength in compression parallel to grain, for example, is about twice as great for a moisture content of 12 percent as for green wood, and drying to about 5 percent moisture content will sometimes triple this value. Increase in strength does not occur unless the moisture content is below the fiber saturation point. The fiber saturation point, which is at approximately 30 percent moisture content, is reached when the free water in the cell cavities has been evaporated and the cell walls are still saturated. As the cell walls continue to lose moisture the strength of the wood increases.

B.2 Moisture Content Correction.

Strength values obtained during testing should be adjusted to a common moisture content value, since variations in moisture content between different specimens existed. In order that these adjustments could be made the following formula from the Wood Handbook (3) was used:

$$\text{Log } S_3 = \log S_1 + \frac{(M_1 - M_3)}{(M_1 - M_2)} \log \left(\frac{S_2}{S_1}\right)$$

where S_1 and M_1 are one pair of corresponding strength and moisture content values as found from test, S_2 and M_2 are another pair, and S_3 is the strength value adjusted to the moisture content M_3. If one

strength value is for green wood, the moisture content that must be used is that corresponding to the intersection of straight lines giving strength-moisture content relations when strength values are plotted as ordinates and moisture content values as abscissas on semilogarithmic paper. This value which is somewhat lower than the fiber saturation point, is designated as M_p. Since the corrections required in this test are to be based on the mean value of moisture content for an individual speciment group (i.e. only 1 pair of M and S) we must use;

$$\text{Log } S_3 = \log S_2 + \left(M_2 - M_3\right) \frac{\log\left(\frac{S_{12}}{S_g}\right)}{(M_p - 12)}$$

where S_g and S_{12} are values pertaining to green wood and wood at 12 percent moisture content, respectively. It is desired to correct 0.03 offset loads to a value at $M_3 = 15\%$. The correction as applied to specimen group 2A1 for the 0.03 offset load is as follows:

S_2 = 0.03 load = 21,100 lbs (previously corrected for specific gravity).

$M_2 = 15.78\%$

$M_3 = 15.00\%$

$Mp = 24\%$

$\frac{S_{12}}{Sg} = 1.86$ (Compression parallel to grain and fiber stress at proportional limit).

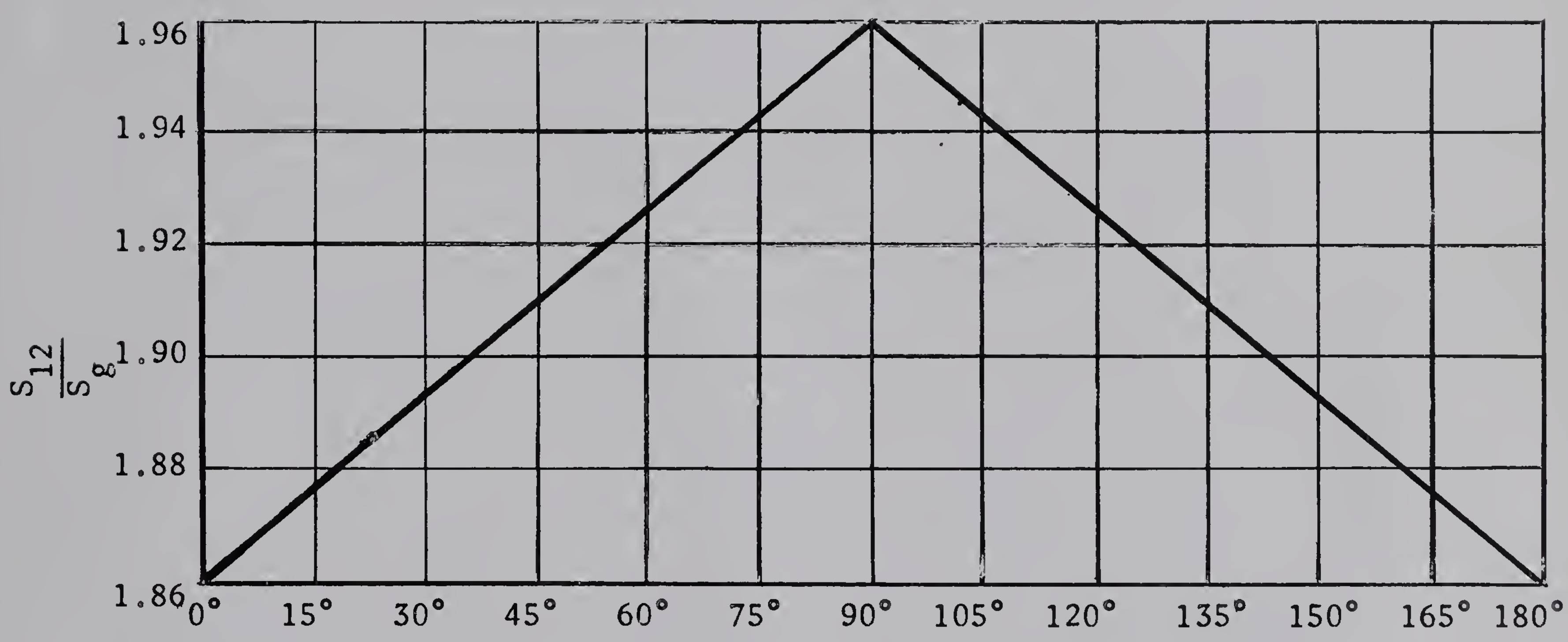
Therefore $\text{Log } S_3 = \log 21{,}100 + (15.78 - 15.00)\ \frac{\log 1.86}{(24 - 12)}$

$S_3 = 22{,}000$ lbs.

The value of $M_3 = 15\%$ was chosen because the National Building Code of Canada, Section 4.3.10(1) uses this value as the maximum moisture content with a modification factor equal to 1.00. For values of moisture content greater than 15% the modification factor is lowered. The value

$\frac{S_{12}}{Sg} = 1.96$ is for compression perpendicular to grain. It is desired that we obtain values that are intermediate as we have compression at various angles to the grain. If a linear relationship is assumed we have as follows:

FIGURE B-1



ANGLE BETWEEN LOAD AND SIDE SURFACE GRAIN.

Any value of $\frac{S_{12}}{S_g}$ may be read directly from Figure B.1.